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THE NORWEGIAN COAST PLAIN.

A NEW FEATURE OF THE GEOGRAPHY OF NORWAY.

THE western part of the Scandinavian peninsula is generally spoken of in geographical descriptions as simply sloping down to the sea. This is not exactly true, for there are, along the coast low, almost level tracts which I propose to unite under the term, The Norwegian Coast Plain. This plain begins on the seaward

FIG. 1. Mount Siggen rising above coast plain.

side with small, naked islands surrounded by shallow water; farther towards the land, it forms a low rim around the higher islands, or constitutes, of itself, rather considerable islands; still farther on, in the outer parts of the fjords, it may be observed along their sides. This coast plain generally rises towards the land. The height is varying; probably one hundred meters may be the uppermost limit. This feature in the geography of our country has previously been noted by the author, and by other

observers, so far as regards portions of the coast, but the observations have not before been brought together as a unit, and viewed as a general feature. The annexed little map (1:400,000) shows one of the coast islands to the south of Bryan, encircled by many other smaller islands and skerries (Fig 2). The coast plain is made black, and the parts rising above it are marked with hachures. In the middle of the large island, one will remark a small white cross. If a person were to stand there and look towards the southeast, he would see the landscape represented in the accompanying sketch (Fig 1), in which the mountain Siggen, and some smaller mountains to the southwest of it are seen rising above the coast plain. The next picture (Fig 3) is probably still more characteristic. It gives a view of some islands at a little distance north of the town, Bergen. The island, which looks like a hat, is Alden, 1,500 feet high. The name of the island group with the three small knolls is Varoc. The low tracts, here represented, are not built of loose materials as one might suppose from the appearance, but are almost all carved from solid rock, and hard rock too, viz., crystalline schists of different kinds, dioritic rocks and conglomerates. The region of Bömmeloe, illustrated above, also has a very complex geological structure.

FIG. 2. Region of Bömmeloe.

These are some instances of the mode of occurrence of the remnants of the coast plain. The plain may be traced along our whole western coast from 50° north latitude to the extremest

frontier towards Russia. A map of it will be communicated to the "Year-book of the Geological Survey of Norway for the years 1892–3. Kristiania, 1894."

The coast plain is rather rough and uneven, with small valleys, and often with innumerable small crags. This roughness of the coast plain, which is partly covered by the sea, has produced the myriads of islands, large and small, and the skerries, or

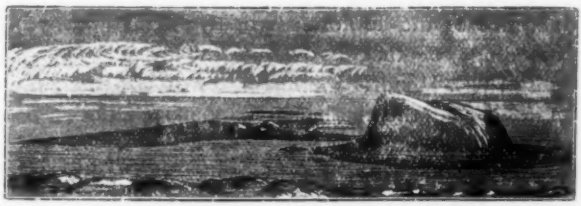

FIG. 3. Mount Alden and the Varoc Islands.

insulated rocks, which are scattered along the greater part of the Norwegian coast. On this coast plain lie the towns of Havanger, Bergen, Tromsoe, and others. Here live hundreds of thousands of people out of our two millions. It is thus seen to be of great importance to our nation. Without it, the whole western coast would be like the bare region east of North Cape, where the coast plain is generally wanting.

The coast plain is a plain of denudation, or a base-level. "It marks a sea-level, to which the land has been reduced by sub-ærial forces." It is glaciated and, in the author's opinion, it has been worked out in periods previous to the glacial period, and in the intervals of that time, when the land was free from ice. The time that has elapsed since the ice-age is too short to be of any importance for the great work performed.

In comparison with the great geographical phenomena here treated, the present strand-lines are small things, though they give evidence that the forces, which made the coast plain, are still working. It has occurred here, as so often elsewhere, that one remarks the small things before the great ones.

HANS REUSCH.

GLACIAL CANONS.

Historical Note.—This paper was presented before the American Association for the Advancement of Science at the Minneapolis meeting, where it was kindly read by Mr. Warren Upham in the absence of the author. A brief abstract was printed in the proceedings of that body for 1883, page 238. Subsequently, Dr. J. E. Hendricks, long editor of *The Analyst*, did the favor of reviewing the mathematical portions, and his suggestions are embodied in a note.

The paper is the fruit of field studies in the Sierra Nevada, mainly in the region about Lake Mono, and of subsequent office work in Salt Lake City, under the direction of I. C. Russell, then of the United States Geological Survey, in 1882 and 1883. The paper was not published because it was recognized that one of the most important phases of ice work (*i. e.*, the work at the bottom of the Bergschrund involved in the formation of cirques and rock basins) was not adequately treated. It was then, as it is now, the opinion of the author that ice work is concentrated and culminates in effectiveness in cirques, whether at the heads of water-carved tributaries (cyms or coombes) or in amphitheatres below ice-falls due to varigradational irregularities in the antecedent water-cut profiles, and that this concentration is proved and the correct analyses of the process suggested by the Bergschrund in the one case and by seracs in the other; but the analysis is difficult, and neither then nor later have opportunities occurred for working it out. Recently this phase of ice work has been taken up by Mr. Willard D. Johnson, who brings to the work a rich fund of observation and an acute and vigorous mind, while at the same time the author finds the promise for the desired opportunity for further study fading away; so it is deemed best to publish in the present form, leaving extension and application to others. It may be observed that, while the treatment

of the subject in this paper is analytic, the work was primarily synthetic and based directly on field observations and inferences in the magnificent field of the southern Sierra.

I.

Glacial cañons are characterized by several peculiar features: 1. They are **U** shaped rather than **V** shaped in cross-profile; 2. Small tributary gorges usually enter at levels considerably above the cañon-bottoms; 3. In longitudinal profile the cañon-bottoms are irregularly terraced—*i. e.*, made up of a series of rude steps of variable form and dimensions,—and some of the terraces are so deeply excavated as to form rock-basins occupied by lakelets; 4. The cañons are sometimes locally expanded into amphitheatres; 5. The cañon-bottom is not always obdurate rock, but may consist of coarse fragmental debris in which individual blocks are as deeply striated and as smoothly polished as are the most solid ledges, though they may rest so insecurely in their positions that a hand can overthrow them; and 6. The volume of glacial debris in moraine and valley deposits is but a small fraction of the cubic content of the cañon from which it was derived.

Of these features the first four suggest that glaciers are most effective engines of erosion, while the last two indicate that glacial erosion is inconsiderable. The source of the apparent discrepance may be sought through analysis of the agencies involved in the development of the four features first enumerated.

II.

Whatever be the physical cause of ice-flow, the motion of a glacier is unquestionably determined by (1) the weight of the ice, (2) the declivity of the channel, (3) the share of potential energy not expended in overcoming internal cohesion, and hence available in producing mass motion, and (4) the friction against bottom and sides of the channel; of which factors the last two (one of which is positive and the other negative) are indeterminate. The united effect of all—*i. e.*, the total sum of potential

energy available in generating movement—may be denominated the *down-stream impulse* of the glacier. Such impulse, in combination with the simple *weight* of ice at any point, constitutes the *intensity* of glacial action at that point.

But, *ceteris paribus*, the measure of rock-grinding is the *friction* between the glacier and its bed. Now such friction is a complex function of the weight and down-stream impulse, and varies with, but probably less rapidly than, their product. The general law of friction, applicable under wide ranges of pressure and velocity, has never, indeed, been clearly formulated; and where the contiguous surfaces are so unlike as rock and ice the friction is scarcely known even in the simplest case.[1] In case of such substances, too, if detached rock-fragments intervene, they will project into the more yielding material and thereby increase the frictional surface; when the slip may either (1) occur in part on each side of the fragments (*i. e.*, the ice may flow over the fragments, while they themselves move at a slower rate over the valley-bottom, as has, indeed, been observed by Niles), or (2) may be confined to the inosculating rock-surfaces. Also, if a continuous sheet of comminuted debris intervene, the movement may be divided between its upper and lower surfaces; and if the intercalated sheet be thick, several planes of slip may exist within it and its own motion become differential. Again, if fragments of large angles and not greatly different diameters project into the ice or lie within a differentially-moving ground moraine, the unequal flow will most rapidly carry forward their summits, initiate rolling, and thus diminish friction (and at the same time, perhaps, produce "fluxion-structure"). It follows that the friction in any given case cannot be even approximately evaluated; and its expression must, therefore, include an indeterminate factor of considerable moment.

But, again, the disposition to attack the glacier-bed is

[1] Tylor found that with a pressure of two pounds to the square inch the co-efficient of friction of ice upon ice was between 0.1 and 0.2, and concluded that glacier motion would be impossible without water to lubricate the bottom. Geol. Mag., Dec. II., Vol., II., 1875, p. 280.

(*ceteris paribus*) measured by the ratio between weight and down-stream impulse; for manifestly, if the weight be in excess, the predominant tendency must ever be to fix and retain in their places all bowlders, pebbles, sandgrains, and smaller particles; when the weight and impulse are as w and v in the diagram (fig. 1) their resultant will tend to retain rather than remove

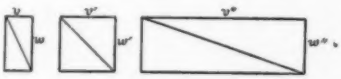

FIG 1.

such fragments, and transportation will be limited to that due to friction and sub-glacial water; when the factors are equal, as are w' and v', their resultant will tend equally to retain and to remove particles, and the effects of friction and flowing water will be counteracted by the greater specific gravity of rock than ice; and when the ratio is as w'' to v'', the disposition will be to overturn and sweep forward all fragments. Also, the weight of ice tends to produce crushing of the rock in a degree probably increasing increasingly with its value. Finally, with increased weight will go increased pressure-liquefaction of the ice, and from this will result the antagonistic effects of reduced friction and augmented transportation. The last two agencies are variable, only very roughly determinate in the ordinary case, and generally of inconsiderable value. They may be thrown together as an unknown factor which, in conjunction with the predominant first agency, constitutes the *effectiveness* of glacial erosion at any point.

The three elements of *intensity*, *friction*, and *effectiveness*, therefore, determine the rate of glacial erosion. To more succintly express their relations, let—

w=weight of ice at any point;
v=down-stream impluse at any point.
s=rock-surface in contact with any vertical prism of ice;
x=unknown factor in friction term; and
z=unknown factor in effectiveness term.

Then, denoting the three elements by their initials:

$$I = w \times v;$$

$$F = \frac{wvx}{s}; \text{ and}$$

$$E = (1 - z)\ \frac{v}{w}.$$ [1]

Obviously, these elements are of unlike value in different parts of the cross-section of a glacial valley, and the rate of erosion is hence differential; but since important unknown factors are involved, no reliable expression either for the absolute rate of erosion at any point, or for the ultimate form of the glacial bed, can be directly deduced. The general tendency of glacial action may, however, be learned from separate consideration of the individual tendencies of the several agencies comprehended.

[1] In the above statement, it has been the purpose to eliminate what is thought to be an element of uncertainty in the extension of the customary formula for friction to quantities so great and so peculiarly conditioned as those involved in the movements of great glaciers. It might be simpler also, as Dr. Hendricks points out, to reduce the determinants of glacier motion to those of positive action—viz., (1), the weight of the ice, (2), the declivity of the channel, and (3), the potential energy available in producing mass motion—by excluding the negative determinant, friction. The down-stream impulse might also be represented by $nw \sin\theta$, n being an unknown factor depending on molecular force, and hence involving temperature, etc. Then, making x the co-efficent of friction, the equations would become:

$$I = w \times nw \sin\theta;$$

$$F = w\ x \cos\theta; \text{ and}$$

$$E = (1 - z) \times \frac{v + F}{w\ x \cos\theta}.$$

Or, introducing the factor $f(v)$ to represent the influence of velocity of flow in determining the friction; the last two equations would become:

$$F = w\ x \cos\theta \times f(v); \text{ and}$$

$$E = (1 - z)\ \frac{v + F}{w\ x \cos\theta \times f(v)}.$$

It will be observed that this modification of the equations for *intensity*, *friction*, and *efficiency* do not materially affect the discussion, and do not in any way detract from the conclusions reached. The original equations are retained, however, in the opinion that they suggest, if they do not actually present, the more direct and serviceable mode of analysis.

It is a pleasure to acknowledge obligation to Dr. J. E. Hendricks, of Des Moines for working out the expressions in this note (January 25, 1885).

In such consideration let the ice be assumed to occupy a previously-formed gorge of the typical **V** form of water-cut cañons.

The weight of the ice varies directly with its thickness, and accordingly increases progressively from sides to center of the gorge. The tendency of this factor is hence to continually deepen the cañon and to perpetuate the **V** form.

Three of the four factors into which down-stream impulse may be resolved are of unequal value in different portions of the width of the glacier, and from such inequality the differential flow of ice-streams results; for from sides to center the weight increases uniformly, the available energy increases increasingly, and the friction probably increases less rapidly than the thickness; whence the impulse at the center must ever remain predominant. But if the ice-stream be conceived to consist of a parallel series of longitudinal vertical laminæ (for in the present discussion the vertical variation of flow is immaterial), it is evident that those at the edges will be retarded by the valley-sides, that the mediolateral laminæ will be equally retarded and accelerated by their unequally flowing neighbors, and that the central lamina will be retarded by the more slowly moving ice on either side; and if the mutual interaction of the various laminæ be considered, that the platted ordinates of flow will form a curved figure, and not a triangle homologous with the cross-section of the gorge (fig. 2). Such indeed is the case of differential ice-flow, as empirically established by Forbes, Agassiz, Tyndall, and other observers; though in the **V** gorge the curve would unquestionably be less flattened than in the **U** gorges within which the measured glaciers lie. On the whole, the disposition of the second factor must be to most energetically attack the valley-bottom, but at the same time to develop concavity of the valley-sides.

Summarizing, it appears that the general tendency of the intensity element is preëminently to deepen the cañon and slightly to transform the **V** to a **U** profile.

Of the factors peculiar to friction, that of indeterminate value doubtless suffers increasing relative diminution as the depth of ice increases, and its platted ordinates (expressed in terms of the valley-profile) will hence form a curve of materially less depth than the triangle formed by the tangents to its extremities (fig. 2). The disposition of the factor is accordingly to widen the gorge and develop the **U** profile.

Fig 2.

With the less lateral velocity common to ice-streams will go reduced lateral friction, and hence erosion, in a ratio corresponding to the velocity curve; and for a second reason, therefore, will concavity of the valley-sides be engendered and developed; though the concurrent disposition will be to deepen the gorge.

Whenever concavity of the valley-sides obtains, the contact surface of the vertical prism will become variable. If, now, friction vary approximately with the pressure of the incumbent ice, the consequent erosion will diminish with the increasing slope toward the edges of the glacier; when the disposition will be to deepen the gorge and restore the **V** form; but if the friction vary more nearly with the contact-area, it will increase with the slope, and the resulting erosion will tend to widen the gorge and, in another manner, to restore the **V** profile. Whichever tendency obtains will, however, be secondary and ever subordinate to that of the principal factors of friction. (Subglacial water will at once reduce friction and promote transportation directly and corrasion indirectly; also it will tend, *ceteris paribus*, to form a continuous film between ice and rock reaching upward to 0.92 of the thickness of the glacier, or, if the glacial surface be highly convex, perhaps quite to its margins. On the whole, then, its

influence in any direction must be slight, and its effect may be disregarded).

Combining the several antagonistic factors, it appears uncertain whether the general tendency of the friction element is to widen or deepen the gorge, but certain that it is to develop concavity of the valley sides and the **U** form of cañon.

Since the third and fourth factors in down-stream impulse (available potential energy and friction) are indeterminate, the problem as to the declivity required to render such impulse equal to the weight at any point in a given glacier, or even as to whether such equality ever obtains in nature, cannot be analytically solved; and very few observations showing the relative value of these components have ever been made. Niles,[1] however, found that in the Great Aletsch glacier the ice usually rides upon projecting rugosities and seldom fills the intervening depressions of its bed, and that a bowlder (itself slowly moving) three feet high had formed an inverted trough thirty feet long in the base of the incumbent ice; whence the down-stream impulse must have exceeded ten times the weight. Bonney,[2] also, in the Glacier des Bois and the Glacier d' Argentiere, found all broad and gentle depressions in the glacier beds filled with impressed ice, the narrower depressions not quite filled, the lee of projecting knobs protected for a distance equal to their height, and bowlders lying *in situ* beyond the present terminus of the ice glaciated above and below (showing that here also motion took place along the two planes), all of which phenomena indicate that, in these glaciers, the down-stream impulse is in excess of weight, but in a less degree than in the Great Aletsch. The several observations then demonstrate (1), that down-stream impulse may greatly exceed weight, and (2), that the relation is variable. All were in the upper portions of the valleys where the declivity is great (15° to 20° in the examples described by Bonney), and where the office of the glaciers is preëminently one

[1] Proc. Boston Soc. Nat. Hist., XIX., 1878, 330; Am. Jour. Sci., XVI., 1878, 366.

[2] Geol. Mag., Dec. II., Vol. III., 1876, 197.

of erosion. Now ordinary valleys, whether occupied by streams or glaciers, are of progressively diminishing declivity from source to terminus; ordinary glacial valleys exhibit successive zones of active erosion, feeble erosion, slight deposition, and abundant deposition in passing from their upper reaches to the broader valleys into which they embouch or upon the plains with which they merge; and in such cases the down-stream impulse must wane to practically nothing at the extremities of the glaciers, and must hence greatly fail of the weight. It follows that at some point (or at diverse points) in every extended glacier-course the components weight and impulse are equal at the centre of the glacier.

Since glacier ice but slightly approaches perfect fluidity and the flow of the center is greatly retarded by the sides, the ratio of impulse to weight (and with it the effectiveness) continually and largely increases from center to sides: if the central effectiveness be just zero, that at the sides will nevertheless remain important; if it be minus centrally, it may still be considerable laterally; and however great may be its value at the center, it must have far greater value at the sides. The disposition, then, will ever be to protect the bottom and equally to attack the sides of the valley; and since the down-stream impulse of the several parallel laminæ forms a curve when platted, so will the disposition also be to form concave valley-sides.

Of the unknown factor in the effectiveness term, the first component (rock-crushing) can be but trivial in the ordinary case, while the second (pressure-liquefaction) exercises antagonistic influences. It may, accordingly, be safely neglected.

Collectively, the tendencies of the third element of glacial erosion are (1) to effectually protect the valley-bottom throughout a considerable portion of the glacier course, (2) to develop the **U** form of canon, and (3) to materially increase the relative width of the gorge.

The fifth feature of glacial cañons is explained by the operation of this element, and in turn establishes the importance of the element.

Recapitulating, it appears that of the several elements involved in glacial erosion, the first tends to deepen the gorge and slightly to develop the **U** form, the second to develop the **U** form, and perhaps very slightly to deepen the gorge, while the third and predominant one tends strongly to widen the gorge and protect its bottom, and less strongly to develop the **U** form. It follows that the general tendency of glaciers must be to widen rather than deepen the valleys they occupy, and to transform **V** to **U** cañons. Also, since the typical **U** gorge is just such as would result from temporary occupancy of a **V** gorge by a glacier, while the ordinary ratio of width to depth is less than would obtain were the gorge eroded by glacial action exclusively, it follows again that the characteristic glacial cañons must be only modified stream-cañons.

This conclusion explains, and is equally and directly corroborated by, the first and sixth features of glacial cañons. It also fully warrants the assumption, in the following as in the foregoing discussion, of originally **V** shaped glacier-beds.

III.

As elsewhere shown,[1] corrasion of a stream is a function of its volume, and, *ceteris paribus*, varies with, but less rapidly than that element. In a region of rapid corrasion then, the main stream must (unless the declivity be materially unlike) more rapidly corrade its channel than does its minor tributary; and the tributary cañon must accordingly enter its principal over a rapid or at least a convex curve in longitudinal profile.

If now the main cañon become filled with ice and be transformed from the **V** to the **U** type by its action, the distal extremity of the tributary will be cut off and the original stream-formed declivity replaced by the precipitous side-wall of the normal glacier valley (fig. 3); and this result will follow whether the tributary be filled with or free from ice, provided corrasion

[1] "The Formation of River Terraces" (recently published in Eleventh Annual Report U. S. Geological Survey, 1891, pp. 259–272).

at the cañon-mouth be not relatively increased in a considerable degree.

It follows that the second feature of the typical glacial cañons may naturally result from temporary occupation of water-cut cañons by ice, and that it does not necessarily argue profound glacial erosion.

IV.

In obedience to the law of varigradation,[1] all and particularly smaller streams tend to depart in a minor degree from uniform gradient, and to develop in their channels a longitudinal profile

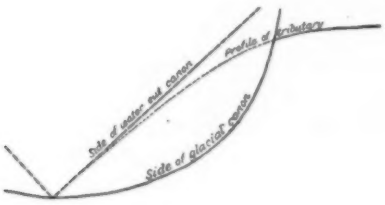

FIG. 3.

of slightly variable declivity; this law finding expression in the alternating pools and rapids of mountain brooks and in the always perceptible and often conspicuous alternations of greater and less declivity in the courses of water-cut cañons.

If now an otherwise uniform **V** cañon of irregular gradient become occupied by a glacier, the flow, varying as it does with the declivity, will become unequal and the ice will tend to accumulate on the planes of low declivity until it approaches a uniform surface slope; when the weight of ice at different points in the medial or other longitudinal plane of the glacier will become variable, and will reach a maximum over the greatest depression (fig. 4). With such increased weight will go (*a*) direct increase of intensity with the augmentation of its principal factor, (*b*) indirect increase of intensity in virtue of the office of weight as a function of the down-stream impulse, and (*c*) direct diminution

[1] Op. cit, p. 295.

of intensity in consequence of the absolutely reduced down-stream impulse; also (*d*) material increase of friction with the augmentation of its principal factor, and (*e*) less material diminution of friction in consequence of the reduced impulse; and finally (*f*), direct diminution of effectiveness with the absolute decrease of impulse, (*g*) indirect diminution of effectiveness in consequence of the relative decrease of the same factor, and (*h*) direct but slight increase of effectiveness in virtue of the operation of the obscure factor of rock-crushing and pressure-liquefaction; or, summarily, increase in intensity, slight increase in friction, and decrease in effectiveness.

Now, in view of the obscure and antagonistic though inter-

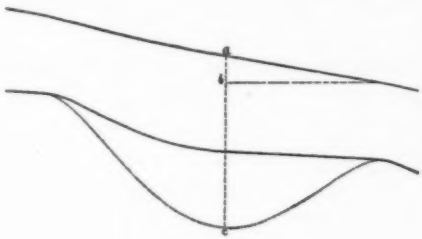

Fig. 4.

dependent relations involved, it is evident that without exhaustive quantitative investigation (impossible in the present absence of knowledge concerning friction between ice and other substances) it cannot be determined in the ordinary case whether the disposition will be to erode the more rapidly where weight increases at the expense of declivity, or where the reverse occurs; but it appears quite certain that where the surface declivity materially exceeds that at the base, and where, accordingly, the impulse is not reduced proportionally to the declivity of the channel, erosion must progressively increase with the weight. If so, the tendency of glaciers must be to cumulatively intensify the irregularities in gradient normal to water-cut cañons.

But corrasion and transportation in any part of a glacier-bed are limited directly by flow of ice and indirectly by coincident

flow of subglacial water. Now, loss of effectiveness through absolute and relative increase of weight must eventually become potent in retarding direct excavation of the depression; also, whenever the depression becomes so considerable as to possess reverse slope toward its distal extremity, gravity will no longer enhance, but instead oppose, direct transportation of detritus; again, with increased depth of depression will go increased cross-section and concomitant and material diminution of velocity and eroding capacity in the ice-stream; and finally, the longitudinal perimeter of the depression must continually increase until the fricton along it approaches and ultimately equals the shearing strength of the ice along its chord, whence the movement of the basal segment must concurrently diminish and gradually cease. In like manner, when the normal slope becomes reversed, gravity will oppose and not enhance transportation by subglacial water; also, as the reverse slope increases, the flow of such water will become sluggish and its capacity diminished; and finally, when the depth of depression below its distal rim reaches 0.92 of the maximum depth of ice (or when *b-c* equals 0.92 *a-c*, fig. 4), the subglacial water will assume static equilibrium, the incumbent ice will suffer flotation, and both corrasion and transportation will practically cease. Thus the excavation of depressions by direct ice-action has a definite though indeterminate limit, and can probably never exceed a moderate fraction of the depth of the ice; and thus also indirect glacial erosion in depressions through the coöperation of subglacial water alike in corrasion and transportation will remain effective until the depth of excavation approaches the thickness of the incumbent ice; whence, in the general case, the measure of maximum excavation of rock-basins is a large fraction of the depth of the glacier.

(Evidently embouchures of valleys, zones of abrupt diminution in declivity, points at which for any reason glaciers terminate for considerable periods, broad cross-valleys beneath continuous ice-sheets, and all localities where the surface slope of the ice materially exceeds the slope of its base, will form as definite loci of active excavation as do the ordinary planes of

low declivity developed by varigradation; and at such localities, accordingly, glacial lakes, the submerged rock-basins characteristic of fjords, and other evidences of energetic ice-action remain after the melting of the ice.)

It follows, then, that the third feature of glacial cañons may result simply from glacial occupation of water-cut cañons; and since in the common mountain region from which the glaciers have completely disappeared the irregularities of gradient peculiar to such cañons are not greatly intensified, while glaciated rock-basins are comparatively rare and of slight depth, it equally follows that the occupation was only temporary, and the sum of glacial erosion relatively inconsiderable.

V.

The immediate effect of the origin of a tributary cañon in a developing drainage-system is the exposure of a greater length of canon-wall to degradation; from which effect in turn results (under certain conditions of homogeneity of terrane and uniformity of altitude in the region, and hence of repeated bifurcation and wide dispersal of the branches of the nascent tributary) the formation of an amphitheatre opening into the main cañon. Then, after the considerable development of the tributary, its disposition will be, as shown by Warren,[1] to dam the main stream and diminish the declivity above its confluence; whereby lateral corrasion will increase at the expense of vertical corrasion there. Thus, by increased lateral corrasion the amphitheatre will ever tend to expand within certain limits immaterial in this discussion. Such amphitheatres, exhibiting the tortuous outlines characteristic of fluvial erosion, have been well illustrated by Dutton,[2] and are common features in many mountain regions.

If now a glacier enter and fill such an amphitheatre, its rate of flow and similarly its rate of erosion on the given area will be

[1] "An Essay Concerning Important Physical Features Exhibited in the Valley of the Minnesota River," 1874–7; and elsewhere.

[2] "Tertiary History of the Grand Cañon District," 1882, Chapter IX, and maps accompanying.

reduced by increase of width and depth; though if (as is probable) erosion varies more nearly with the weight than the velocity, its amount will increase absolutely, and the expanded valley will tend in a stronger degree than that measured by the ratio of the inverse volumes to assume the general form characteristic of contracted glacial gorges. As in the contracted gorge, too, lateral effectiveness will remain predominant; but the effective energy of the glacier will be mainly concentrated upon the obstructive angles, spurs, and cusps of the irregular water-carved walls, and the removal of these and the rounding out of the amphitheatre will be in the first work of the glacier. Again, the partial rigidity of the ice-mass will lead to culmination of pressure about the distal extremity of the amphitheatre, and to consequent extension of its boundaries beyond the confluence of the tributary by which its water-fashioned prototype was originated.

It follows that glaciated amphitheatres may be merely water-carved valley expansions modified by temporary ice-action into regularity of contour (as are, for instance, those of the Faeröe Islands[1]), and that they do not necessarily argue profound glacial erosion.

VI.

Summarizing the chief effects of the several agencies involved in the development or the characteristic features of glacial cañons, it appears that temporary occupancy of a typical water-cut cañon by glacier ice will (1) increase the width, (2) change the **V** to a **U** cross-profile, (3) cut off the terminal portions of tributary cañons, and thus relatively elevate their embouchures, (4) intensify certain irregularities of gradient in the cañon-bottom, (5) excavate rock-basins, (6) develop amphitheatres, and, in general, transform such cañon into an equally typical glacial cañon. It follows that these features do not necessarily imply extensive glacial excavation or indicate that glaciers are superlatively energetic engines of erosion.

W J McGee.

[1] J. Geikie, "Geology of the Faeröe Islands," Trans. Roy. Soc., Edin., 1882.

FOSSIL PLANTS AS AN AID TO GEOLOGY.

Paleobotany, together with all the other branches of paleontology, admits of subdivision into two lines, or fields of study—the biological and the geological—depending upon the prominence that is given to the one or the other of these subjects. The biological study concerns itself with the evolution of the vegetable kingdom, that is, with the tracing of the lines of descent through which the living flora has been developed. The geological side of paleobotany has two phases, one of which concerns itself with the associations, time relations, and distribution of the plant forms which constitute the successive floras of the geological ages and form an important element in the life history of the earth, while the other is concerned principally with the use of fossil plants as stratigraphic marks, but also with any aid that may be rendered in elucidating the many intricate problems which geology presents. The latter, or geological aspect, is almost exclusively the phase of the subject to which the present paper is devoted.

Before passing to an elaboration of the claims that paleobotany may have as an aid to geology, it may not be out of place to call attention to the fact that the successful use of fossils as stratigraphic marks is, or at least may be, entirely independent of their correct biological interpretation. It makes not the slightest difference to the stratigraphic geologist whether the fossils upon which he most relies are named at all, so long as their horizon is known and they are clearly defined and capable of recognition under any and all conditions. They might almost as well be referred to by number as by name, although, of course, every paleontologist seeks to interpret to the best of his knowledge the fossils that he studies. He may, probably often does, make mistakes in his attempts to

understand them, but from the very nature of the case this must be so. They must all be studied in the light of recent forms, which, in the case of wholly extinct groups, is a matter of great difficulty.

On the other hand, to the historical geologist who makes use of fossils in unravelling the succession of geological events, the correct biological identification is of the greatest importance, for upon this rests his interpretation of the succession of faunas and floras that have inhabited the globe. These principles are tersely stated by Dr. C. A. White in one of his essays on "The Relation of Biology to Geological Investigation."[1] He says: "If fossils were to be treated only as mere tokens of the respective formations in which they are found, their biological classification would be a matter of little consequence, but their broad signification in historical geology, as well as in systematic biology, renders it necessary that they should be classified as nearly as possible in the same manner that living animals and plants are classified."

PRINCIPLES OF PALEOBOTANY.

There are certain broad, fundamental principles upon which the science of paleobotany rests. Some of these are so simple as to be almost axiomatic, while others are less evident and have only recently been recognized. It has been disregard of these principles that, in the past, has often brought paleobotany into disrepute. Each of the departments upon which geology calls for aid has to acknowledge limitations, and so paleobotany has bounds beyond which it can not be legitimately asked to go. But it is confidently predicted that when the evidence has been sifted, and the limitations, as well as the just claims, have been properly adjusted, the evidence derived from fossil plants will be as reliable as that supplied by other branches of paleontology.

One of the most important principles has been admirably

[1] Ann. Rept. U. S. National Museum, 1892, p. 261.

expressed by Professor Ward.[1] It is that "Great types of vegetation are characteristic of great epochs of geology, and it is impossible for the types of one epoch to occur in another." For example, the presence of a dicotyledonous leaf, no matter how fragmentary, is proof positive that the stratum containing it is Mesozoic or younger. It can not possibly be older. Again, the presence of a single scar of Lepidodendron or Sigillaria, when not in redeposited strata, is just as strong evidence that they came from a Paleozoic horizon, since not a single specimen has ever been found later than the Permian.

The application of this principle is often of the greatest aid in geology, for, as frequently happens, the strata of a region have been much displaced and distorted, and it is no uncommon thing to find Paleozoic rocks occupying the positions that should seemingly, normally be taken by Cretaceous or Tertiary strata. The stratigraphy may be so exceedingly complicated as to render it quite impossible to distinguish Paleozoic from Mesozoic strata. Nor can petrography be always depended upon to supply distinguishing marks. In such cases, which are by no means purely hypothetical, a single fossil plant may serve to set at rest all possibility of dispute.

An example of this kind is furnished by the well-known case of the beds of Chardonet in France, "studied by Élie de Beaumont in 1828 and positively referred to the Mesozoic, but in which fossil plants of the genera Calamites, Sigillaria and Lepidodendron were identified by Brongniart."[2] At that time the principle under discussion had not been recognized and Brongniart was "inclined to admit" that these genera might have occurred in the Mesozoic, although long before his death he recognized it and realized that the genera indicated beyond question a Paleozoic age.

Another important principle, bearing upon the limitations of paleobotany, is what has been called the law of homotaxis.

[1] Principles and Methods of Geologic Correlation by means of Fossil Plants. Am. Geol., Vol. IX., 1892, p. 36.

[2] Ward, l. c.

As long ago as 1853 Pictet, in his then celebrated *Traité de Paléontologie*, presented a number of general principles, among them being one, the so-called eighth law, which bears directly upon the present question. It is as follows: "Contemporaneous deposits, or those formed at the same epoch, contain identical fossils. Conversely: deposits which contain identical fossils are contemporaneous." This was modified by Schimper,[1] the celebrated French paleobotanist, who added that deposits "formed at the same epoch, contain floras, if not completely identical, at least homologous, and consequently deposits that contain identical or homologous floras are contemporaneous." But Huxley appears to have been the first (1862) to formulate clearly the objections to this law. He pointed out that while the succession of life in widely separated localities may be shown to have been similar, it by no means follows that the identical elements in these widely separated localities were strictly contemporaneous. To this he applied the term *homotaxis*, which implies that the plants and animals of widely separated places may have had practically the same process of development or succession, yet when the element of time is considered they may have been far from identical. As an example it may be mentioned that the most abundant and typical genus of plants in the Carboniferous rocks of Australia and Tasmania is Glossopteris, a genus which is not represented in rocks of similar age in Europe, but occurs in Upper Mesozoic beds of that region.

This, it will be readily understood, applies to localities widely separated, as for example between continents that are not intimately connected, or that are now and have been for a long geological period separated by insurmountable barriers to immigration, such as oceans and mountain chains. The plants originating within a given area or the ones inhabiting a locality adapt themselves to the environment, and these can only extend their distribution readily to areas in which the conditions are similar. Hence if the particular locality in which a species has been developed is separated from other areas, perhaps as well suited

[1] Traité de Pal. Vég., Vol. I., 1869, p. 100.

to its growth, by a natural barrier such as a lofty, unbroken mountain chain or a broad expanse of water, the chances are against the species finding its way quickly to the remote areas. As an example of this may be cited the flora of the Hawaiian Islands. This flora, exclusive of the species introduced since the discovery of the Islands by Cooke in 1779, embraces 860 species of phanerogams and vascular cryptogams. Of this number no less than 653, or 75.93 per cent. are endemic or peculiar to the Islands. On account of the vast expanse of the Pacific by which the Hawaiian Islands are separated from the nearest land, the flora has been unable to extend its distribution.

It is but reasonable to suppose that similar conditions existed in past geologic ages, but by the obliteration of barriers, such as the shallowing of the water or emergence of direct land connection, the plants may have been enabled to invade new territory, and thus extend from area to area or from continent to continent. If now an examination is made of the remains of vegetation in two or several widely separated areas, the succession will be found to have been the same, but they may not have been strictly contemporaneous.

What now is the deduction to be made since the formulation of this principle regarding the value of paleontologic evidence? Does it immediately follow that all correlations based upon similarity of fossil remains fall to the ground? By no means. It has simply introduced an additional element of caution into the problem of correlation between widely separated areas. And even here it has been, and must continue to be, of the greatest importance, for, as Professor Ward has well said,[1] "What we possess is the general fact that a similar flora once existed in two parts of the world very widely separated, and until some other facts are discovered which complicate and vitiate such a conclusion, it is both safe and useful for the geologist to regard the two deposits as belonging to the same geologic age. There are certain limitations within which this must be true, and when these limitations are recognized the paleontologist may as safely

[1] loc. cit. p. 47.

draw his conclusions as he could before the law of homotaxis had been formulated."

Thus, while admitting the possibility of homotaxial relations existing between the floras of widely separated areas, certain correlations, on the basis of simultaneity, of extensive series of beds in different countries, have stood the test of time. On this subject Sir William Dawson has given important evidence.[1] He says: "I desire, however, under this head, to affirm my conviction that, with reference to the Erian and Carboniferous floras of North America and Europe, the doctrine of 'homotaxis,' as distinct from actual contemporaneity, has no place. The succession of formations in the Palæozoic period evidences a similar series of physical phenomena on the grandest scale throughout the northern hemisphere. The succession of marine animals implies the continuity of the sea-bottoms on which they lived. The headquarters of the Erian flora in North America and Europe must have been in connected or adjoining areas in the North Atlantic. The similarity of the Carboniferous flora on the two sides of the Atlantic, and the great number of identical species, proves a still closer connection in that period. These coincidences are too extensive and too frequently repeated to be the result of any accident of similar sequence at different times, and this more especially as they extend to the more minute differences in the features of each period, as, for instance, the floras of the Lower and Upper Devonian, and Lower, Middle, and Upper Carboniferous."

USE OF FOSSIL PLANTS IN RESTRICTED AREAS.

Turning now from the correlation of strata in widely separated localities, we come to that part of the field in which geology is likely to receive its most valuable aid from paleobotany, viz.: the identification of horizons and their correlation within restricted areas. While the phase of the subject which has just been discussed may be of much importance when the final volume of the geology of the world comes to be written, it can

[1] Geological History of Plants, p. 262.

never, if we are to judge by the recent trend of attempts at widespread correlation, hold the position of importance that correlation within circumscribed areas does. The minor subdivisions of the geological time-standard established for Europe, for example, is found to be of only limited application in North America, and attempts to bring them into complete harmony are little short of wasted energy. But with limited or natural areas the case is far different.

Organic remains are unquestionably of first importance in identifying formations. The study of the mineral composition and lithological characteristics of formations must be abandoned as the sole means necessary for their identification. Recourse must be had to the fossils to set the stratigraphist aright, for as Professor J. W. Judd has said,[1] "We still regard fossils as the 'medals of creation,' and certain types of life we take to be as truly characteristic of definite periods as the coins which bear the image and superscription of a Roman emperor or of a Saxon king." Of the various kinds of such remains fossil plants occupy relatively as important a position as those afforded by most of the other biological groups.

It is by no means uncommon to find that fossil plants are almost the only organic remains present in a formation, but if they are not, the evidence they afford, when properly interpreted, confirms that obtained from other groups of organic life, as the following examples will show.

As an illustration of the first mentioned condition, viz. : that in which plants only are present in numbers sufficient to entitle them to exclusive consideration, the Dakota group offers an exceptionally fine example. This formation is four or five hundred miles wide, more than a thousand miles long and of considerable thickness, yet not a single vertebrate fossil, and hardly ten species of invertebrates have thus far been detected throughout its vast extent. The Dakota flora, however, is one of the most extensive and thoroughly known fossil floras. According to Lesquereux[2]

[1] Nature, Vol. XXXVII., 1888, p. 426.

[2] Flora of the Dakota Group, p. 14.

460 species have been described from this formation, of which number no less than 394 are peculiar, that is, have never yet been found outside of it. A very large number of these plants are so characteristic that their discovery in strata of unknown age would settle at once their reference to this horizon. An illustration of this is just at hand. A single dicotyledonous leaf was some time ago described,[1] under the name of *Sterculia Drakei*, from the upper sandstone of the Tucumcari beds near Big Tucumcari Mountain, New Mexico. This plant has lately[2] been referred to as the only dicotyledon known from the Trinity beds of the Comanche series, a reference that is, so far as we know, highly improbable, for Fontaine, in his descriptions of all of the plants now known from these beds[3] finds no trace of dicotyledons. A glance at the figure of the Tucumcari plant suffices to show that it is *Sterculia Snowii*, a well-known, very abundant, and characteristic plant of the Dakota group. This leaf, together with what is now known of the position of the rocks containing it, is amply sufficient to settle the age of this portion of the Tucumcari sandstone, a conclusion agreeing perfectly with the results several times set forth by Professor R. T. Hill from stratigraphic and paleontological grounds. The Potomac formation furnishes a parallel example. This series of beds, extending in almost unbroken line from New Jersey to Alabama, contains a known flora of 737 species, over 80 per cent. of which are peculiar.

An example of the complete accord existing between fossil plants and other organic remains in determining age is offered by the Trinity Division of the Comanche Series of Texas, the flora of which, so far as known, has recently been worked out by Fontaine.[4] The particular beds in this series, from which the plants came, have been named the Glen Rose or alternating strata, by Professor R. T. Hill, and their age determined by marine invertebrates, as Neocomian or basal Cretaceous. The flora consists of twenty-

[1] Geol. Survey of Texas, 3d Ann. Rept., 1891, p. 210.

[2] Am. Geol., Vol. XII., 1893, p. 327.

[3] Proc. U. S. National Museum, Vol. XVI., 1893, p. 261–282.

[4] Op. cit., p. 281.

three species of plants characteristic of the lower Cretaceous, and appears to find its closest resemblance in the older portion of the lower Potomac. Professor Fontaine's results are summed up as follows: "The Glen Rose or alternating strata, in which the fossil plants are found, contain an abundant marine fauna, from the evidence of which Professor Hill had concluded that its age was Neocomian or basal Cretaceous. No fossil plants had hitherto been found in the Comanche series, and the evidence of its age was derived wholly from the animal remains. The discovery of plants in it was, then, of special importance, for it enabled us to compare the evidence of the plant-life with that of the animal life. It is interesting to find so close an agreement. This agreement adds one more proof of the value of fossil floras in fixing the age of the strata in which they are found."

The age of the strata exposed at Gay Head, on the western end of Martha's Vineyard, has been the subject of discussion and speculation by geologists for nearly or quite a hundred years, and the question has only recently been settled. In general the strata have been correlated with the similarly appearing strata of Alum Bay in the Isle of Wight, the position of which is fixed as middle Eocene. It is true that certain Cretaceous shells had been found, but they were not in place, and so intermingled with recent forms, that it was concluded that the age could hardly be other than lower or middle Tertiary. As late as 1889 Professor N. S. Shaler[1] decided, upon purely stratigraphic grounds, that "this part of the Tertiary series is certainly of later Miocene or Pliocene age.

In 1890 Mr. David White visited Martha's Vineyard, and was fortunate enough to find and collect a considerable series of fossil plants from the strata in question. The results of this study[2] showed beyond all doubt that they were of Cretaceous age, many being identical with the plants of the Amboy clays of New Jersey. "The Gay Head flora," Mr. White concludes, "indi-

[1] Seventh Annual Report U. S. Geol. Survey, 1885–6, p. 332.

[2] Cf. Am. Jour. Sci., Vol. XXXIX., 1890, pp. 93–101.

cates an age certainly Cretaceous, and probably middle Cretaceous."

Here, then, is an example of the value of a few fossil plants in determining the age of a series of beds where a hundred years of study from the stratigraphic side had failed to accomplish conclusive results.

The flora of the so-called Laramie beds of the Rocky Mountain region has also been the subject of much discussion and controversy. By certain of the older writers it was referred to the Tertiary, by others to the Upper Cretaceous. Recent investigation has shown, however, that several distinct horizons were embraced in what has been known as the Laramie. The tendency appears to be to restrict the term "Laramie," at least in the Colorado district, to the lower or older beds, and accordingly the Post Laramie beds have been differentiated and given independent names. As fossil plants are the most abundant organic remains present in this series of strata, their bearing on the question of the age and differentiation of the beds is important. No dependence can be placed on the earlier determinations of the distribution of the plants, for the reason that the different horizons had not then been distinguished, and the plants are often recorded from a locality at which several of the horizons are present and plant-bearing. It has been necessary to go over all the original material and determine by studying the matrix, and by duplicate collections, the actual horizon to which they belong. In this way the status of 285 species now known to occur in these beds has been settled. In Colorado and New Mexico, the only area in which the interrelations have yet been worked out, it appears that there is a flora of 165 species, of which number 62 belong to the true Laramie and 103 to the Denver beds, and with only 7 species common to both. This proves beyond question that the Laramie and Denver beds are distinct, and that they possess, in certain clearly defined species of fossil plants, readily recognizable stratigraphic marks.

The deductions made from this datum point, viz.: the thorough study of the flora of the Colorado Laramie and allied

formations, are already important. Of these two or three examples may be cited.

The Post-Laramie beds of Middle Park, Colorado, have been made the subject of an investigation by Mr. Whitman Cross. After reviewing historically the opinions of various writers as to the age of these beds, he discusses exhaustively the results of recent work in this field. He reviews the fossil flora at length, correcting many obvious errors of locality and horizon into which the early collections had fallen, and finally presents a revised list of the plants known certainly to have come from the Middle Park beds. In the light of the revisions of the Laramie and Denver floras, nearly 75 per cent. of the species enumerated in this list are found to be common to the Denver beds. The complete agreement of the paleobotanical with the other geological evidences is well shown in conclusions of Mr. Cross, which are as follows: "The unconformable relationships, lithological constitution, and fossil flora all indicate the equivalence of the Middle Park and Denver beds. No evidence seems to indicate any other correlation."[1]

The Laramie and Post-Laramie beds of Montana have been studied by Mr. W. H. Weed.[2] His paper gives an account of a series of beds heretofore embraced within the Laramie, and covering the greater portion of the State of Montana east of the Rocky Mountains. It is shown stratigraphically that the thickness of some 13,000 feet of strata belong to three formations: the Laramie, the overlying Livingston, and the higher Fort Union beds.

Fossil plants occur in all three of these formations, and from their study it is made clear that the Livingston beds occupy the same position in Montana, with reference to the Laramie, as do the Denver beds in Colorado. Of 22 species of plants found in the Livingston beds no less than 17 are found either exclusively in the Denver, or have their greatest development in this formation.

[1] Proc. Colorado Scientific Soc., 1892, p. 26 of reprint.

[2] Bull. U. S. Geol. Survey, No. 105.

Large numbers of huge vertebrate remains, only known from "The Laramie of Wyoming," fortunately have fragments of fossil plants adhering to them, from the study of which important light will be thrown on the age of the beds in which they are contained.

Along the Missouri river in the vicinity of Great Falls, Montana, there is exposed a considerable thickness of mainly brown, sandstone rocks. They have been eroded by the river into more or less of a cañon, and are the material in which the falls have been developed. From their lithologic appearance, but mainly upon stratigraphic grounds, these rocks have been referred by geologists to the Dakota group. On going down the river they disappear under the Fort Benton shales, and are consequently in the stratigraphic position of the Dakota, but the recent discovery of plant-beds near Great Falls has shown the impossibility of such reference. The plants are typically lower Cretaceous, and have been positively identified by Newberry with the Kootanie of Canada. By this a part at least of the so-called Dakota goes to the lowest Cretaceous.

In a similar way a part of the supposed Dakota of the Black Hills has been shown by Professor Ward,[1] purely on paleobotanical evidence, to belong to the lower Cretaceous.

The Foreman beds in the Taylorville region, Plumas county, California, were determined to be of Rhætic age from the fossil plants, a determination agreeing perfectly with the stratigraphy.[2]

The copper mines near Abiquiu, New Mexico, were identified as Triassic by the plants found in and about the roof of the openings.[3]

The employment of fossil plants in practical mining exploitation is well shown by the results obtained by Grand' Eury and Zeiller in Southern France.

In the Department of Gard the mining of coal is one of

[1] Journal of Geology, Vol. II., No. 3, pp. 250–266.

[2] DILLER: Bull. Geol. Soc. Am., Vol. 3, p. 373.

[3] FONTAINE & KNOWLTON: Proc. U. S. Nat. Mus., Vol. XIII., 1890, p. 282–285. NEWBERRY: Rep. Expl. Ex. in 1859 under Macomb. Wash., 1876, p. 140.

the most important industries. In this district there are a number of veins of workable coal which have been formed at different epochs. These veins are separated from each other by barren strata of varying thickness, and are always accompanied by certain characteristic plants, especially ferns and allied forms.

In the valley of the Grand' Combe there are a number of coal openings, among which may be more especially distinguished those of the Sainte Barbe and Grand' Combe. M. Zeiller, the engineer-in-chief of the mines, from a study of the fossil plants which accompany the two layers, determined that the first deposit, viz.: that of Sainte Barbe, was older than the other. With this knowledge in his possession, M. Zeiller did not hesitate to counsel the company that by sinking a shaft at a place called Richard, just outside of the valley of the Grand' Combe, they would reach a new seam of coal corresponding to the Sainte Barbe. The shaft was sunk for 400 meters, but as only barren strata were encountered it was abandoned, and it was reserved for Grand' Eury to prove the correctness of Zeiller's prediction.

Grand' Eury, in a general study of the coal basin of Gard by means of fossil plants, determined that the coal of Sainte Barbe was deposited at the same epoch as that of Bessèges, from the fact that the same plants occurred at both localities. In the same manner he proved that the coal of Grand' Combe was of the same age as that of Gangières, but he also found that between the beds of Bessèges and Gangières there was a barren series of strata approximating 600 meters in thickness. It therefore became evident that the shaft at Richard had been abandoned too hastily, and work was again prosecuted, and at a depth of 731 meters the vein of coal, 4.80 meters thick, corresponding to the Sainte Barbe, was reached.

STUDY OF FOSSIL PLANTS BY MEANS OF INTERNAL STRUCTURE.

By far the larger proportion of fossil plants are preserved in the form of impressions or casts of leaves, fruits, stems, etc., only comparatively few having the internal structure so preserved as

to admit of their study under the microscope. The parts usually exhibiting internal structure are stems, branches, roots, and other normally hard organs, yet in exceptional cases every part of the plant, including the leaves, buds, and flowers, are so perfectly preserved that they may be as successfully studied as though living. An example of this kind is afforded by the Carboniferous groups of Cordaites, found in a state of silicification in central France.

Plants that are so preserved as to retain their internal structure, admit of closer study and characterization than is usually attained for other plant organs. So valuable is this method that Professor W. C. Williamson, the distinguished English paleobotanist, was led to say[1] "that no determinations respecting fossil plants can have much absolute value save such as rest upon internal organization; that is the basis upon which all scientific recent botany rests, and no mere external appearances can outweigh the positive testimony of organization in fossil types." Therefore, when it is possible to obtain plant remains with the internal structure preserved, it may be safely set down that they will afford valuable and reliable data for stratigraphic identification.

The study of the internal structure of fossil plants is yet young in North America, and while a broad field remains for future investigation, enough has already been accomplished to show its value. A few examples may be cited:

In 1888, *Araucarioxylon Arizonicum* was described from the Trias (Shinarump group of Powell) of New Mexico. The same species has been found characteristic of the Trias of North Carolina[2] and of the copper mines near Abiquiu, New Mexico.[3]

In his paper on the geology of Skunnemunk Mountain, Orange county, New York,[4] Professor C. S. Prosser relies upon

[1] On the Organization of the Fossil Plants of the Coal Measures. Roy. Soc., London. Phil. Trans., Vol. 161; 1871; p. 492.

[2] RUSSELL: The Newark System, p. 29.

[3] FONTAINE and KNOWLTON: Notes on Triassic plants from New Mexico. Proc. U. S. Nat. Mus., Vol. XIII., 1890, pp 281–285.

[4] Trans. N. Y. Academy Science, Vol. XI., June, 1892.

the fossil plants, especially *Nematophyton crassum* known from the study of its internal structure, to prove the Middle Devonian age of that part of the geological section.

Certain well-defined species of fossil wood are characteristic of particular horizons, as for example *Cordaites Ouangondianus* (Dn.) Göpp., which is confined to the Middle Erian (Devonian); *C. Halli* (Dn.) Kn., and *C. Newberryi* (Dn.) Kn., are confined to the Hamilton Group; *Dadoxylon annulatum* Dn., found only in the middle coal-measures, etc.

SUBSIDIARY USE OF FOSSIL PLANTS.

Among the many relatively subsidiary problems connected with the application of paleobotany to geology, the use of fossil plants as tests of past climate occupies an important place. Plants are unable to migrate like animals when the temperature of their habitat becomes unfavorable, and they must either give way, or adapt themselves gradually to the changed conditions of environment. Hence, fossil plants have always been accorded first place as indices of past climates. "They are," as Dr. Asa Gray has said, "the thermometers of the ages, by which climatic extremes and climate in general through long periods are best measured." [1]

The wide geographical distribution and similarity of appearance of Paleozoic plants, especially coal-measure plants, argues beyond question a uniformity of climatic conditions. The absence of rings of growth in the Carboniferous conifers shows, as long ago pointed out by Witham, that the seasons, if such they could have been called, were either absent or not abrupt, and it is not until the Trias is reached that the clearly defined rings of growth bear indisputable evidence of the existence of seasons.

"Heer, as a result of his examination of the Swiss Tertiary plant-beds, is led to the interesting conclusion that in certain cases it is possible to detect the regular recurrence of seasons by the constant association in the same strata of fruits or leaves

[1] The Nation, No. 742, September 18, 1879.

of plants whose living representatives are known to agree closely in their period of vegetation."[1]

Fossil plants may also, in certain cases, be used to indicate the character of the water in which the deposits were laid down. Thus, the finding of an abundance of marine diatoms in an undisturbed formation is proof that they were deposited in salt water, and the finding of diatoms only known in connection with hot springs is equal proof of former thermal activity. As an example of the last may be mentioned the finding of a large number of species of diatoms in beds of infusorial earth in Utah that are now found living in a hot spring (temperature 163° F.) in Pueblo Valley, Humbolt County, Nevada, showing that the fossil specimens must have been accumulated in a hot lake of about the same temperature.[2]

It is quite commonly argued that during Carboniferous time there was present such a large amount of carbon-dioxide that it produced a thick veil, hiding or at least largely obscuring the direct sunlight. This extreme view is not wholly sustained by fossil plants, for the presence of strongly developed palisade parenchyma in certain leaves, as in Cordaites and many ferns, which can only be formed in direct sunlight, shows conclusively that there must have been at least gleams of sunlight penetrating the so-called veil.

LEGITIMATE FIELD OF PALEOBOTANY.

Before leaving the subject it may be well to point out some of the responsibilities resting with the geologist who would avail himself of paleobotanical aid in the determination of horizons. In the first place, if it is worth while to ask an opinion of the paleobotanist, it is surely worth while for the geologist to spend time enough when making the collection he would submit, to procure at least a fair representation of the fossil flora of that horizon. To expect the paleobotanist to unravel a stratigraphic problem that has perhaps puzzled the trained stratigrapher and

[1] A. C. Seward. Fossil Plants as Tests of Climate, p. 20.

[2] Am. Journ. Sci., 3d ser., Vol. IV., 1872, p. 148.

petrographer, by the examination of a mere handful of specimens gathered hastily as a "last thought," is asking too much! There is a limit to what can legitimately be expected of paleobotany, just as there is a limit to all knowledge.

Again, it has frequently been a practice among geologists to submit a collection of fossil plants without indication of the specific information desired or even of the locality whence the specimens came. This is done presumably with the idea that the paleobotanist, being unembarrased with previous information, would be the better able to give an unbiased opinion. This again is wrong, and under such circumstances the paleobotanist would be amply justified in declining to express an opinion. Unless he can be placed in possession of all the information known to the geologist, or, what is better, have an opportunity of examining the relations of the horizons himself, he should hesitate before passing judgment. Of course, as pointed out under the discussion of principles, certain broad conclusions may be made instantly, such as the presence of dicotyledons proving an upper Mesozoic age, or Lepidodendra and Sigillaria arguing a Paleozoic age. These, however, are not usually the problems presented, but close questions of age, as, for example, the Miocene or Pliocene age of the auriferous gravels of California.

It has been argued by many, especially botanists and geologists, that it is undesirable to give names to fragmentary and seemingly indeterminable plant remains. When a definite name is given it implies, it is argued, a more exact knowledge than is often times possessed; a view that in many cases is undoubtedly correct. But the name is given, when the fossil cannot be made out satisfactorily, for purely practical reasons. It embodies, or should, the best possible judgment as to its nature and systematic position, and serves as a convenient basis of future mention of it without tedious circumlocution.

The foregoing examples have been given somewhat in detail, for the purpose of showing what has already been done with fossil plants, and to indicate the lines along which, it is hoped, increased assistance will be rendered geology in the future. These

examples have designedly been confined almost exclusively to North America, and while additional ones might have been given within this area, but more particularly in other countries, enough has been presented to indicate that paleobotany may be relied upon to supply a series of stratigraphic marks in every way as reliable for the cases they cover as those supplied by any of the other branches of paleontology.

F. H KNOWLTON.

WAVE-LIKE PROGRESS OF AN EPEIROGENIC UPLIFT.[1]

To the ancient Greeks the word *epeiros*, specially applied to the land lying next north, signified also, in general, any mainland or continental area, as contrasted with islands or their own peninsular country. From this word Gilbert has recently supplied to our science the terms *epeirogeny* and *epeirogenic*, to designate the broad movements of uplift and subsidence which affect the whole or large parts of continents and of the oceanic basins.[2] Previously the correlative terms *orogeny* and *orogenic* had come into use, denoting the process of formation of mountain ranges by folds, faults, upthrusts and overthrusts, affecting comparatively narrow belts and lifting them in great ridges, while the epeirogenic movements of the earth's crust produce and maintain the continental plateaus and the broad depressions which are covered by the sea.

During the closing part of the Tertiary era and the present Quaternary or Psychozoic era, both epeirogenic and orogenic changes have been in progress on many portions of the earth, and on a scale of grandeur probably never before surpassed. Where these movements have raised continental regions or mountain districts to much greater altitudes than they now retain, if they were situated within the range of prevailing air currents abundantly laden with moisture and were at latitudes so far from the equator that the precipitation was chiefly snow throughout the year, they became for a time enveloped by ice-sheets, which have left the surface strewn with glacial and modified drift. Fjords, and now submarine continuations of river

[1] Presented before the World's Congress on Geology, auxiliary with the Columbian Exposition, Chicago, August 25, 1893. This paper is an attempt to answer, by a definite example, a portion of the inquiries in an editorial of the JOURNAL OF GEOLOGY, Vol. I, page 298, April–May, 1893.

[2] "Lake Bonneville," Monograph I., U. S. Geological Survey, 1890, p. 340.

valleys, attest for the northern two-thirds of North America such late Tertiary and Quaternary epeirogenic uplift at least 2,000 to 3,000 feet above the present height of this continent; for the British Isles, Scandinavia, and probably the greater part of Europe, an uplift 1,000 to 4,000 feet higher than now; and for the western side of Africa within a few degrees both north and south of the equator, 3,000 to 6,000 feet.[1] Attending the subsidence of these areas, greatly increased altitudes have been given by folding, rifts, and upthrusts, to large portions of the highest mountain systems of the world, as the Alp-Himalayan and Andes-Cordilleran belts.[2] The most recent of all mountains, excepting volcanic cones, probably is the lofty St. Elias range, according to Russell's observations; and the belt in which this is a part has an extent of two-thirds of the circumference of the globe, from Cape Horn to Alaska, the Aleutian Islands, Kamtchatka, the Kuriles, Japan, and the Philippine islands, intersecting the eastern part of the Alp-Himalayan belt near Krakatoa, in the earth's most volcanic and seismic district.

The drift-bearing areas in North America, in Europe, and in Patagonia, which at the end of their epoch of gradual elevation and fjord erosion had become deeply covered by land-ice, sank under its weight until when the ice melted away they mainly stood somewhat lower than now. The shores of the sea at that time in the St. Lawrence and Ottawa valleys, in the basin of lake Champlain, and about Hudson bay, have been again uplifted,

[1] J. W. SPENCER, Bulletin, Geol. Soc. Am., Vol. 1., 1890, pp. 65–70 (also in the Geol. Magazine, III., Vol. 7, 1890, pp. 208–212). J. D. DANA, Am. Jour. Sci., III., Vol. 40, pp. 425–437, Dec., 1890, with an excellent map of the Hudson submarine valley and fjord. G. DAVIDSON, Bulletin of the California Academy of Sciences, Vol. 2, 1887, pp. 265–268. T. F. JAMIESON, Geol. Mag., III., Vol. 8, pp. 387–392, Sept., 1891. J. Y. BUCHANAN, Scottish Geographical Magazine, Vol. 3, 1887, pp. 217–238.

[2] H. B. MEDLICOTT and W. T. BLANFORD, Manual of the Geology of India, Calcutta, 1879, Part I., pp. lvi, 372; Part II., pp. 569–571, 667–669, 672–681. J. LE CONTE, Am. Jour. Sci., III., Vol. 32, pp. 167–181, Sept. 1886; Bulletin, Geol. Soc. Am., Vol. 2, 1891, pp. 323–330; Elements of Geology, third edition, 1891, pp. 250–266, 589. J. S. DILLER, Eighth An. Rep., U. S. Geol. Survey, for 1886–87, pp. 426–432; JOURNAL OF GEOLOGY, Vol. 2, pp. 32–54, Jan.–Feb., 1894. I. C. RUSSELL, National Geographic Magazine, Vol. 3, 1891, pp. 172, 173. W. UPHAM, Appalachia, Vol. 6, 1891, pp. 191–207 (also in Pop. Sci. Monthly, Vol. 39, pp. 665–678, Sept. 1891).

but only to a comparatively small amount, from 200 to 500 or 600 feet, after the departure of the ice-sheet. In Scandinavia, according to the investigations of Baron de Geer, the postglacial uplift has varied from a minimum of 100 feet or less at the southern extremity of Sweden, to a maximum exceeding 1,000 feet in the central part of the peninsula.[1] Likewise in South America, along a distance of 1,200 miles, from the Rio Plata to Tierra del Fuego, the land has been elevated since its glaciation, the general extent of this movement in Patagonia, as observed by Darwin, being between 300 and 400 feet.[2]

The special case of an epeirogenic movement progressing like a wave, which it is the purpose of this paper to consider, is this latest, moderate uplift of North America, and especially of its central belt comprised in the Mississippi and Nelson river basins, from its depression at the close of the Glacial period. While the ice-sheet was retreating, this great area was rising as fast as its burden was removed. Close upon the wasting ice-border there followed a wave of permanent uplift of the land on which it had lain. First the loess district along the Mississippi and the upper part of this basin were elevated; next, the southern half of the area of the glacial lake Agassiz; later, its northern half; and last of all, the country enclosing Hudson bay, with which also was probably associated, as very late in its uplift, the region of the great Laurentian lakes, including lake Champlain, and of the Ottawa and the St. Lawrence. From south to north and north-east the wave of elevation advanced, and, according to Dr. Robert Bell, the rise of the land has not yet ceased about James and Hudson bays, where, in the central part of the glaciated region, we must suppose that the ice-sheet had its greatest thickness and was latest represented by lingering remnants. Having thus outlined our theme, let us return and look more

[1] Bulletin, Geol. Soc. Am., Vol. 3, 1891, pp. 65–68, with map of the late glacial marine area in southern Sweden; Proceedings of the Boston Society of Natural History, Vol. 25, 1892, pp. 456–461 (also in the Am. Geologist, Vol. 11, pp. 23–29, Jan., 1893).

[2] "Voyage of H.M.S. Beagle," chapter viii.

fully at the evidence of this progressive earth movement in the chronologic and geographic order of its successive portions.

Between the chief time of deposition of the Mississippi loess and the formation of the prominent moraines east of the Wisconsin driftless area, there intervened an uplift of the upper Mississippi region to a vertical extent estimated by Chamberlin and Salisbury as probably 800 to 1,000 feet.[1] On the western portion of the driftless area and southward to the Gulf of Mexico, the loess had been spread by very slowly flowing river floods, and partly in temporary lakes, due to the greater depression of the basin toward the north, while in the opposite direction the subsidence was insufficient to carry the low southern part of the valley beneath the sea level. The ensuing uplift probably scarcely increased the altitude of that southern area about the mouth of the Mississippi, but thence it extended northward as a differential epeirogenic movement, raising the depressed country of the central and northern portions of this great river basin several hundred feet. As a result of the changed slope, in the former place of the quiet water whose sediment was the loess, strong currents, bearing sand and gravel, flowed down the valleys from the ice-front when it amassed the moraines mentioned in Wisconsin. The duration thus represented has been supposed to comprise a long interglacial epoch, but the observations on which this belief rests seem to me to admit a different interpretation.

On the drift border, in some parts of southern Illinois and Indiana, the loess was deposited, according to Salisbury, immediately after the till which immediately underlies it, and was in part contemporaneous with the till. As soon as the ice-sheet retired from the positions where this relationship exists, the glacial drift was covered by this finer silt of the modified drift supplied by streams that flowed from the melting and retreating ice.[2] In the northeastern part of Iowa, McGee similarly finds the

[1] "Preliminary Paper on the Driftless Area of the Upper Mississippi Valley," Seventh An. Rep., U. S. Geol. Survey, for 1884–85, pp. 199–322.

[2] "The Geology of Crowley's Ridge" (1891), Geol. Survey of Arkansas, An. Rep. for 1889, Vol. 2, pp. 228, 229.

loess to have been deposited while the ice-sheet that spread the upper portion of the early till was melting away. The very remarkable paha of that district, which are eskers of loess, were accumulated while the waning ice-sheet walled them in at each side.[1] That the later part of the loess deposition was contemporaneous with the formation of the Altamont moraine, belonging to the later drift and marking its limits, I ascertained in northwestern Iowa, where this moraine along a distance of seventy-five miles, from Guthrie county northwestward to Storm Lake, is bordered on its west side by an expanse of loess as high as the crests of the morainic hills, while its elevation above the expanse of till eastward is from fifty to seventy-five feet. During the time of deposition of this part of the loess the ice-sheet reached to the Altamont moraine and was a barrier preventing the waters by which the loess was brought from flowing over the lower area of till that reaches thence east to the Des Moines river.[2] On three widely separated tracts the loess, as elsewhere the coarser portions of the modified drift forming sand and gravel plains, was in progress of deposition upon successive areas as fast as the ice-sheet supplying these stratified drift beds receded. Immediately after the land was bared by the retreat of the ice, and even while the ice itself occupied the adjoining land, the loess was being laid down, contemporaneous successively with the early till on the southern border of the drift, with the till of intermediate age in northeastern Iowa, and with the later till enclosed by the Altamont moraine. The loess deposition I believe to have been mainly continuous, accompanying the gradual and widely extended but wavering departure of the ice-sheet from its farthest boundary to this outermost of the conspicuous morainic belts.[3]

[1] U. S. Geol. Survey, Eleventh An. Rep. for 1889-90, pp. 435-471.

[2] Geol. and Nat. Hist. Survey of Minnesota, Ninth An. Rep. for 1880, pp. 307-314, 338.

[3] The interpretation of the loess and glacial history of the Mississippi basin which I here present differs widely, it must be acknowledged, from the opinions of Professors Chamberlin and Salisbury, and Messrs. McGee and Leverett, to whom we owe so much of the critical investigation of this area. These observers have been led by their

While the ice was retreating and supplying the loess, the land thus uncovered and relieved from the ice weight had been gradually rising, until it had attained approximately its present height in Wisconsin, Iowa, and southern Minnesota, before the formation of the moraines. This altitude has endured, excepting minor

studies to conclude that between the deposition of the early till in southeastern Illinois, with its accompanying loess, and that of the till and attendant paha or eskers of loess in northeastern Iowa, there intervened a very long and diversified history of glacial recessions and re-advances, including at least one prolonged interglacial epoch. A summary of these views in relation to the glacial succession in Ohio is well stated by Mr. Frank Leverett in this JOURNAL OF GEOLOGY, Vol. 1, pages 129-146, Feb.-March, 1893. From my early study, "Modified Drift in New Hampshire" (Geol. of N. H., Vol. 3., 1878, chapter i., pp. 3-176, with maps and sections), and from my later work on the Glacial Lake Agassiz, I am strongly impressed with the conviction that the deposition and ensuing erosion of the drift, both till and stratified beds, as the loess, went forward very rapidly. What these authors have ascribed to interglacial epochs, one or more of them of great length, seems to me to be more probably referable to geologically very short stages of fluctuation of the mainly waning ice-sheet.

Professor Salisbury, in the report cited, shows that there were two successive deposits of till, and a corresponding division of the loess, on and near to the boundaries of the drift; these seem to me probably due to two closely consecutive stages of ice advance, instead of the long time interval which he thinks to be indicated. Again, in the report on northeastern Iowa, to which reference was given, Mr. McGee clearly shows, chiefly by the forest bed intercalated between two sheets of till, that likewise there the ice advanced twice, with a considerable intervening time, which he supposes to have been far longer than the Postglacial epoch. To my mind, however, the forest-covered borders of the Malaspina glacier or ice-sheet in Alaska leave no doubt that forest beds enclosed in till may be due to oscillations of the ice-front within distances of no more than a few miles or even less than one mile, and that they may have required no longer interval than a few tens of years or at most a century, sufficient for the forest growth, between the times of ice retreat and re-advance.

When the depression of the ice-loaded land brought it down to so low altitude that the borders of the ice-sheet began to be melted more rapidly than they received increase by snowfall and onflow from the thicker central portion of the ice, a general recession of the glacial margin ensued. On the southern part of the drift in the Mississippi basin no continuous moraines were accumulated, and I attribute their absence principally to the attenuated condition of the ice there and its lack of a steep border. During the glacial retreat, wherever the wavering climate caused the mainly waning ice-border to remain nearly stationary during several years the vigorous outflow of the ice to its then steep frontal slope brought much drift, forming belts of irregular morainic hills and ridges, and leaving many hollows which enclose lakes. The fluctuations of the general glacial retreat seem to me to have been due principally to variations of snowfall, some long terms of years having much snow and prevailingly cool temperature, therefore allowing considerable glacial re-advance, while for the greater part other series of years favored rapid melting and retreat.

and unimportant oscillations, from that time until now. The beginning or earliest known stage of the progressive elevatory wave probably thus raised the northern half of the Mississippi basin to a variable amount ranging from 100 feet or less to 500 feet or more. It was practically completed, for this area, previous to the accumulation of the outer and earlier moraines in the series of many which mark pauses in the further recession of the ice-sheet. Thenceforward the glacial melting appears to have been more rapid than before, giving to the ice steeper frontal gradients whereby its drift was amassed more commonly in hills, ridges, and lake-enclosing hollows, and especially in the very irregularly knolly and hilly moraine belts.

The rapidity of the glacial recession and of this ensuing epeirogenic uplift in its wave-like advance upon the area of the glacial Lake Agassiz, extending nearly 700 miles from south to north in the basin of the Red river and of Lake Winnipeg, surpasses all previous knowledge in what it reveals concerning the mobility of the earth's crust. The postglacial duration of Lake Michigan and its companion great lakes of the St. Lawrence has been shown, by numerous independent but well agreeing observations and estimates, to be no longer than 6,000 to 10,000 years. Now the amount of wave erosion on the shores of Lake Michigan and the resulting accumulation of beach sand, heaped into dunes upon large areas about the south end of the lake, must exceed, by a ratio of 10 : 1 or 20 : 1, the corresponding wave action in its total amount at all the successive levels held by Lake Agassiz during its history, which accordingly must be comprised within some such time as 1,000 years or perhaps less.[1] During this geologically very short time, the ice was melted away upon the distance of 700 to 1,000 miles from the middle of the west side of Minnesota to James and Hudson bays, and the Lake Agassiz basin was differentially uplifted mostly 300 to 500 feet, to the height which it has ever since retained without appreciable later change. To understand the wave-like devel-

[1] Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, Vol. 4, for 1888-89, pp. 50, 51 E.

opment of this uplift, it will be needful to consider it first for the southern half and afterward for the northern half of the glacial lake area.

About thirty successive levels of Lake Agassiz have been recognized by its beaches. A considerable number were due to the gradual erosion and lowering of the outlets, and to their changes of place and direction, first toward the south and later toward the northeast; but probably more than half of this whole series of lake levels are distinctly exhibited only upon the central and northern portions of the lacustrine area, being due chiefly to its differential uplift increasing from south to north, and in a small degree to the decrease in the gravitative attraction of the waning ice-sheet. The five well defined beaches near the south end of this ancient lake, named in descending order the Herman, Norcross, Tintah, Campbell, and McCauleyville beaches, formed at the successive levels of southward outflow as the channel was deepened, are each found to be represented, when they are followed northward, by two, three, or more, so that near the international boundary and in Manitoba, they become subdivided into no less than seventeen beaches, marking the stages of the subsidence of the lake and in larger proportion of the differential elevation of the land. Nearly as many other lower shore lines record the stages of the lake while it outflowed northeastward. My surveys of these shores, with exact mapping and leveling, extend more than 300 miles from the south end, to lakes Winnipeg and Manitoba and the Riding Mountain.[1]

In this southern half of the whole extent of Lake Agassiz, the shore of its highest or Herman stage, as represented at the north by the uppermost of its divided beaches, has now a northward ascent of about 35 feet in the first 75 miles north from Lake Traverse, which lies in the old channel of southward outlet, about 60 feet in the second 75 miles, and about 80 feet in the

[1] Geological and Natural History Survey of Minnesota, Eighth An. Rep., for 1879, pp. 84-87; Eleventh An. Rep., for 1882, pp. 137-153, with map; Final Report, Vol. 1 (1884), and Vol. 2 (1888). U. S. Geol. Survey, Bulletin No. 39 (1887), pp. 84, with map. Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, Vol. 4, for 1888-89, Part E, pp. 156, with maps and sections.

third distance of 74 miles to the international boundary. Its whole ascent thus in 224 miles is 175 feet, by a slope which increases from slightly less than a half of a foot per mile in its southern third to slightly more than one foot per mile in its northern third. This beach extends only a short distance farther north, having been formed when the ice-sheet lay there as the northern boundary of the lake; but the second of the Herman beaches, slightly lower and later, reaches as far northward as to the limit of my exploration, in the vicinity of Gladstone, Manitoba, and Riding Mountain, and in this distance of 308 miles, from Lake Traverse to the latitude of Gladstone, it has an ascent of 265 feet. In the four successive nearly equal parts of its extent from south to north, namely, 75 miles, again 75 miles, then 74 miles, and lastly 84 miles, it rises respectively about 35, 50, 80, and 100 feet; and almost the whole of this change of the old beach, from its horizontality at the time of formation, has been produced by the gradual uplifting of the lake basin while the ice-sheet was retreating from it.

The considerably later upper Norcross beach rises in these distances about 25, 35, 55, and 70 feet, amounting to 185 feet in the entire 308 miles. The upper Campbell beach has ascents of about 10, 15, 30, and 35 feet, or 90 feet in all; and the lowest of the three McCauleyville beaches, marking the latest stage of southward outflow of Lake Agassiz, ascends about 5, 10, 15, and 20 feet or a total of 50 feet. It is thus seen that far the greater part of the uplift of this area had been accomplished before the formation of the Campbell and McCauleyville beaches.

Beyond the limits of my leveling, portions of nearly all the shore lines of Lake Agassiz below those of the Herman series have been observed and mapped by Mr. J. B. Tyrrell, of the Canadian Geological Survey, at localities in northwestern Manitoba and eastern Saskatchewan, bordering the northern half of this lacustrine area.[1] From a careful comparison of the eleva-

[1] Geol. and Nat. Hist. Survey of Canada, An. Rep., new series, Vol. 3, for 1887-88, Part E, pp. 16, with map; Vol. 5, for 1889-90, Part E, pp. 240, with map, sections, and illustrations from photographs.

tions of the beaches noted by Mr. Tyrrell with those determined by my surveys at the south, I am enabled to correlate very satisfactorily the two sets of shore lines. The northern continuations of the successive lake levels from the upper Norcross beach to the Niverville beaches, which mark the latest stages of the glacial lake, just before the recession of the ice-sheet from the district crossed by the Nelson river permitted it to be reduced to the Lake Winnipeg, are thus identified upon a region lying 50 to 200 miles beyond the area examined by me.

Along the base of the escarpments of Riding and Duck mountains, where Mr. Tyrrell has traced the beaches and determined their heights for a distance of fifty miles between Valley and Duck rivers, that is, between latitudes 51° 15′ and 52° N., it is found that a very important differential elevation, increasing from south to north about three feet per mile, took place after the Campbell and McCauleyville beaches were formed, since they are thus remarkably changed from their original horizontality. It is clearly shown here that the uplifting was not uniformly proportionate and regular for the whole area of Lake Agassiz. The chief movements of elevation of its southern and central part, as far to the north as Gladstone, seem not to have extended farther, at least in their full proportion. The district next to the north along an extent of 120 miles, to the north end of Duck mountain, was perhaps only so far disturbed by these movements as was necessitated to connect the rise of the country on the latitude of Gladstone with the continuing condition of maximum subsidence on the latitude of the lower part of the Saskatchewan and the north end of Lake Winnipeg. But there ensued in this district, after the date of the Campbell beach, a great differential elevation, giving to these late shore lines two or three times more northward ascent than that of the Herman beach from Lake Traverse to Gladstone; and the total change in level of the highest observed beach, probably representing the upper Norcross stage, situated at Pine river, on latitude 51° 50′ to 52° N., is approximately 400 feet, as compared with this shore line at Lake Traverse, about 420 miles distant to the south. Nearly

the whole uplift of the northern part of the basin was accomplished, however, while the ice-sheet was still a barrier of the lake, for the Niverville beach at the Grand Rapids of the Saskatchewan is only slightly higher than on the Red river, 250 miles to the south.

The southern and central part of the lake basin, reaching north to Gladstone, had been raised nearly to its present height during the first third or half of the period of the entire duration of Lake Agassiz. Then followed a time, during the second third of the lake's existence, in which the district that includes Riding and Duck mountains and extends north to the mouth of the Saskatchewan was being rapidly uplifted. But this later northward and northeastward advance of the wave of upheaval had passed beyond the Saskatchewan before Lake Agassiz was lowered to Lake Winnipeg, as is shown by the nearly level Niverville beaches. The rise of the land approximately to its present height is thus known to have followed close upon the glacial recession by which the land was relieved of the ice weight.

Latest of all, when Lake Winnipeg and the Nelson river had come into existence, the shores of Hudson and James bays were raised 300 to 500 feet from their late glacial marine submergence.[1] The remnants of the ice-sheet in that region were not melted away until much later than the glacial retreat from the northern United States and Manitoba. Moving onward with the departure of the ice, the uplifting wave of the earth's crust has raised the basin of Hudson bay 300 to 500 feet since the sea was admitted to it, and the upheaval there is not yet completed. Though doubtless slower than at first, it is still in progress, according to Dr. Bell's observations, at a probable rate of five to seven feet per century. During this last portion of the epeirogenic uplift of our continent from its Champlain depression, the whole area of Lake Agassiz, as shown by the still horizontal

[1] DR. ROBERT BELL, Geol. and Nat. Hist. Survey of Canada, Reports of Progress, for 1871-72, p. 112; for 1875-76, pp. 340; for 1877-78, pp. 7 and 32 C and 25 CC; for 1878-79, p. 21 C; for 1882-84, pp. 26-32 DD; Annual Reports, new series, Vol 1. for 1885, p. 11 DD; Vol. 2, for 1886, pp. 27, 34, and 38 G.

Niverville beaches, lay undisturbed. The loess region of the Mississippi valley, having been earliest and permanently uplifted, suffered no further change during the progressive elevation of the Lake Agassiz basin; and that in its turn was at rest while the great area of Hudson bay has been undergoing elevation.

Having already shown that the entire duration of Lake Agassiz was about 1,000 years, we must conclude that the uplift of its area, probably to heights ranging from 100 feet to mainly about 500 feet, occurring first at the south and later at the north, took place, when in most rapid movement upward, at rates of a half a foot to one foot per year. A century, therefore, would comprise an elevation of 50 to 100 feet. The movement, however, was evidently more or less intermittent, with pauses of slower uplift or stages of rest, when the successive beach ridges were formed. Nowhere else in the records of present or past epeirogenic movements of any region have so rapid changes of level of large tracts been ascertained; and these changes seem clearly to have occurred through a gradual deformation of the earth's crust by quiet flexure, not by faulting and earthquakes, which would break the regularity and continuity of the ascents of the beaches when traced long distances. The preglacial epeirogenic uplifts of drift-bearing areas, also apparently taking place without faulting, was probably much slower; but their final depression beneath the ice-sheet may have been even considerably more rapid. Very sudden and great, yet not seismic, uplifts of extensive areas, as supposed by Prestwich for southern England and Wales, to account for the "head" or "rubble drift,"[1] and by Shaler for the coastal border of New England, to explain the origin and preservation of the kames,[2] seem, at least in my opinion, to be physically impossible.

The probable nature of epeirogenic movements, in their dependence on conditions of the earth's crust and interior,

[1] Quart. Jour. Geol. Soc., Vol. 48, 1892, pp. 263-343, with many sections and a map.

[2] U. S. Geol. Survey, Seventh An. Rep., for 1885-86, pp. 310, 320, 321; Bulletin No. 53, 1889, "The Geology of Nantucket," pp. 44, 45.

remains to be briefly noticed. Between the epochs of mountain-building by plication, the diminution of the earth's mass produces epeirogenic distortion of the crust, by the elevation of certain large areas and the depression of others; and these effects have been greatest just before relief has been given by the formation of folded mountain ranges. Two epochs have been preëminently distinguished by extensive mountain plication, one occurring at the close of the Paleozoic era, and the other progressing through the Tertiary and culminating in the Quaternary era, introducing the Ice age. During the last, besides plication and overthrust faulting of the Coast range, the St. Elias range, the Alps, and the Himalayas, a very extraordinary development of tilted mountain ranges, and outpouring of lavas on an almost unprecedented scale, have taken place in the Great Basin and the region crossed by the Snake and Columbia rivers. With the culminations of both of these great epochs of mountain-building, so widely separated by the Mesozoic and Tertiary eras, glaciation has been remarkably associated, and indeed the ice accumulation appears to have been caused by the epeirogenic and orogenic uplifts of continental plateaus and mountain ranges. These processes are well consistent with Dana's doctrine of the general permanence of the continents and oceanic basins; for upheaval of an ocean bed would not diminish but increase the earth's volume. The late glacial and postglacial uplift of North America from its Champlain depression, by the wave-like movement which has been here described, seems an effort of the earth to regain the state of isostasy, or flotation of the crust on the heavier mobile interior, which is capable of flow, whether it be solid or molten.

WARREN UPHAM.

THE OCCURRENCE OF ALGONKIAN ROCKS IN VERMONT AND THE EVIDENCE FOR THEIR SUB-DIVISION.

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GEOGRAPHY.

THE area of the Pre-Cambrian rocks forming the subject of this paper[1] is quite limited in comparison with the probable extent of these rocks in Vermont. Personal reconnaissance work has detected them existing from the town Stratton on the south to Rochester on the north, a distance of fifty miles. In only a part of this area has detailed work been done, viz.; from Weston to Chittenden. On the east the district is bounded by Plymouth Valley; on the west by Rutland Valley, an area of about 240

[1] The work, of which this paper forms a partial result, was done under the immediate supervision of Mr. Raphael Pumpelly, then in charge of the Archæan Division of the United States Geological Survey, to whom my greatest thanks are due for useful counsel and advice. It is not to be understood that he is necessarily in perfect accord with me in any views advanced here.

square miles. This area has a maximum width on the south of ten miles and a minimum width on the north of four miles. The delimitation of the Pre-Cambrian as just given is only approximate, as in many localities data for its separation from overlying rocks are lacking.

TOPOGRAPHY.

The Geological Survey has lately issued topographic maps of nearly all the territory embraced in the above-outlined area; in them the pronounced relief of the country is well shown. These maps are the Rutland and Wallingford sheets. An inspection of the topography reveals a line of high elevations on the west, with steep slopes to the east, and steeper slopes commonly on the western side. This line of mountains extends from the southern limit of the Wallingford sheet to the northern limit of the Rutland sheet, and is only broken by narrow transverse valleys where lateral streams come in from the east or southeast and join Otter creek in the Rutland valley. On the east side of the area a similar range of high mountains extends the same distance, but coalesces with the western line in the northern part of the Rutland sheet. The convergence of the two lines is geologically dependent on a narrowing of the series of folds, which originally mantled over the central part of the area. North of Ludlow mountains an offset to the east occurs which carries the line slightly to the east of the Wallingford sheet.

It will be noticed on the Wallingford sheet that there is a central area between the border line of mountains of relatively much lower elevations. From Copperas hill in Shrewsbury one observes that the mountains appear to encircle him with a line of much higher elevations. In a country of strong relief one is always impressed with a sense of being in the centre of a series of elevations of greater height than those in the immediate vicinity. But from Copperas hill the impression is borne out by a glance at the topographic maps. On the east and west are the two lines of mountains just described; to the south, but farther away, the country begins to rise towards the high peaks of Stratton and Somerset; to the north, just north of the town of Shrewsbury

the high summits of Mendon, Killington and Shrewsbury extending east and west shut off the view in this direction. The lowest part of this amphitheatre is just northwest of Cuttingsville where Mill Creek has cut down to an elevation of 1000 feet above the sea. Killington Peak marks the highest point to the north, 4241 feet. The Central Vermont Railroad finds the lowest pass in the southern part of the range through this amphitheatre at Summit Station, 1500 feet above the sea.

Standing on the summit of Killington a wilderness of mountains meets one's view; the Taconic Mountains on the west and southwest; the Adirondacks to the northwest; far away northeast the White Mountains are plainly visible and the sharp outlying peaks, Monadnock, Kearsarge and Wachusett are seen to the southeast. The summits of all these mountains, with the multitude of peaks in Vermont, have the appearance of a remarkably uniform height about which numerous narrow valleys are seen; their relatively uniform height can safely be referred to an ancient base-level plain, in which upon elevation the north and south gently-flowing streams were quickly cut along the linear limestone belts, hastening and causing the development of the torrential lateral streams that flow east and west from the Green Mountain divide. It is to this torrential character of the streams and the schistose nature of the rocks that the sharp, angular topography in large part seems to be due. Rutland and Plymouth valleys, some twelve miles apart on either side of the range, are deeply cut in limestone—the former at Rutland to a depth of 500 feet above the sea. The great cutting power of the streams flowing into this valley from the east is thus seen to be due to a fall of over 3000 feet in a distance of six miles. The Green Mountain divide is about midway between these two valleys. Relatively less pronounced topographical features characterize the amphitheatre; sharp, high elevations occur, which are capped by more resistant rocks than those making up the main central area. It is between the lower rocks of this central depression and the formation along the east and west borders and to the north that an unconformity separating the rocks

below the Olenellus quartzite into two periods is thought to occur.

GEOLOGY.

Outline of the views previously held regarding the structure and age of the Green Mountains.—As far back as 1845, Adams in his first Annual Report on the Geology of Vermont[1] referred to the "Primary" system the rocks of the main range of the Green Mountains as far as the state boundary, and eastward. Among the rocks mentioned under this head which occur in the area studied by me are Green Mountain Gneiss, Mica Slate and Talcose Slate. In this report these horizons are placed below the Stockbridge limestone and the associated quartzite of the Taconic, but their relative age is confessedly unknown. In his second annua report,[2] however, he leaves the problem as to whether these are "Taconic," "Primary," or "Metamorphic," an open question, but still inclines towards a belief in their primary origin. This belief is inferred from his statement that the evidence goes to show that the limestone and quartzite of Plymouth valley on the east side of the range is equivalent to the Stockbridge limestone and quarzite on the west side, making the core of the Green Mountains the older. Adams in no place makes the statement that the belt of primary rocks represents the axis of the range, and it is doubted if he had any clear conception of the relations of the rocks on the east and west sides of the Green Mountain divide. In 1847, however, Edward Hitchcock gave two sections in his text book of Geology[3] of the Green Mountain anticline partially and completely folded as we see it to-day. The anticline is represented as overturned slightly to the west, with a flat crest and a rude fan-shaped cross-section; the text[4] mentions that the strata grow newer as one goes westerly, although apparently the series is descending. Such a conclusion reached at that time is the happy result of a coincidence of schistosity and stratification at

[1] p. 62.

[2] Second Annual Report on the Geology of Vermont. Adams, 1846, p. 168.

[3] Elementary Geology, Edward Hitchcock, 1847, figs. 27 and 28, p. 37.

[4] Opus. cit., p. 36.

the localities examined by him ; in a general way the structure is that of an overturned series of folds, of an extremely complicated nature. These sections were made particularly to illustrate the structure of Hoosac Mountain, and the structure suggested in 1847 finds its verification in 1889[1] in Massachusetts, as far as the overturning of the anticline to the west is concerned. At that time little reference was made to the age of the rocks exposed along the axis, but they were mentioned as probably older than the Lower Silurian, while their relation to the younger rocks was not considered.

Zodack Thompson, in 1856, in considering the "Taconic System," makes reference to the structure of the rocks along the Green Mountain range[2].

He remarks that "one of the most marked peculiarities in the geology of Vermont is found in the general dip of the stratified rocks, which is, with a few trifling exceptions, toward a synclinal axis extending north and south near the center of the Green Mountain range." He notes a general westerly dip on the east side of the range, and an easterly dip on the west side. However, the question as to whether the Green Mountain rocks are really primary or post-Taconic was with him still in doubt, but he states that the weight of the evidence points towards the latter view, or more recent age.

In 1868, T. Sterry Hunt, after a study of the literature, while discussing Vermont geology, comes to much the same conclusion as Thompson.[3] To use his own words: "All the evidence, palæontological and stratigraphical, as yet brought forward, affords no proof of the existence in Vermont of any strata (a small spur of the Laurentian excepted) lower than the Potsdam

[1] See part 3, "Geology of the Green Mountains in Massachusetts," by R. Pumpelly, J. E. Wolff, T. Nelson Dale, and Bayard T. Putnam. Monograph U. S. Geol. Survey. Submitted in 1889. Not yet issued.

[2] Preliminary Report on the Natural History of the State of Vermont. Augustus Young. 1856. Extract from Zodack Thompson's address on the Natural History of Vermont. App. 6, p. 67.

[3] On some points in the geology of Vermont, T. Sterry Hunt, Am. Jour. Sci., 2d series, Vol. XLVI., 1868, p. 229.

formation * * * ." The gneiss of the Green Mountains is by him and by the geological survey of Canada referred to the Quebec group and a synclinal structure is assigned to the range probably largely on the basis of the views of Thompson. It is thus seen that Adams' suggestion of the anticlinal nature of the mountains and their "primary" age are passed over, as well as the more recent work of the elder Hitchcock, to which reference is made below.

Anything like a close study of the Green Mountains was not attempted until 1861, when the two Hitchcocks finished their work on the geology of the state.[1] Under the head of Azoic Rocks,[2] Charles H. Hitchcock places the Vermont rocks occurring east of the Stockbridge limestone as far as the Connecticut river, and includes therein the basal quartzite of Emmons' Taconic system, although the elder Hitchcock admits finding therein traces of life in the shape of Scolithus and a species of Lingula[3] which were not deemed sufficient evidence to warrant classifying this horizon with the fossiliferous rocks. The younger Hitchcock divided the Azoic rocks as follows: Gneiss (Adams' Green Mountain Gneiss) hornblende schist, mica-schist, clay-slate, quartz-rock, talcose schist, serpentine and steatite and saccharoidal limestone. The most western member, the quartz-rock or quartzite with its associated conglomerate is mapped as extending the whole length of the state. Just north of the area studied by me it is represented as thinning out and giving place to "talcose conglomerate."[4] On the east side of the mountains a narrow strip is colored in extending through the towns of Plymouth and Ludlow. Lithological similarity is used as a basis for the correlation of the conglomerate, which underlies the "quartz-rock" at Wallingford with the Shawangunk Grit or Oneida Conglomerate of New York. The quartzite or quartz-rock is referred for

[1] Geology of Vermont, 1861, 2 volumes.

[2] Opus. cit. Vol. I., pp. 452 to 453.

[3] Opus. cit. Vol. I., p. 500.

[4] Opus. cit. See geological map of Vermont. Pl. I., Vol. I.

palæontological reasons to the Medina, and the hypothesis is advanced that by the removal of silicates by circulating waters metamorphosis of the quartz-rock to the conglomerate has taken place. Reference will be made again to this conglomerate in the following pages. Under the head of Gneiss, rocks of great variation are grouped. Eight principal varieties dependent on accessory minerals such as hornblende and epidote are enumerated. The gneiss is represented as a slightly curving band, extending from the Massachusetts line nearly to the north end of the state, gradually narrowing to a point. In the south-eastern part of the state another shorter lense is mapped, but this has not been explored by the writer. The relations of the gneiss to the conglomerate or quartz-rock are not dwelt upon, but many phases are assigned to metamorphosed Lower Silurian rocks, while the probability that even older rocks may be exposed along the anticlinal axis in the range proper, or to the east is regarded as a possibility. A deficiency of feldspar is remarked upon; because of this peculiarity, according to Hitchcock, Adams called it "Green Mountain Gneiss to distinguish it from true gneiss."[1] Seven years later (1868) C. H. Hitchcock abandoned his theory as to the age of the quartzite,[2] and in a new classification refers it to the Potsdam group. The Talcose conglomerate is placed in the "Lauzon" group of the Lower Silurian, while to the Eozoic system the Green Mountain gneiss is assigned. In placing the gneiss in the Eozoic he does not infer that it necessarily is older than the Cambrian or Huronian. Several reasons are enumerated for referring it to this system, the strongest one being the evidence afforded by the occurrence of pebbles in the Talcose comglomerate at the base of the Potsdam derived from gneissic rocks. An unconformity beneath the Potsdam points to the Eozoic age of the lower rocks.[3]

The suggestion made by Adams (above mentioned) that the Green Mountains are an anticlinal fold, is followed, in

[1] Opus. cit. Vol. I., p. 454.

[2] The Geology of Vermont, Proc. Amer. Asso., 16th meeting, 1868, p. 120.

[3] Opus. cit. p. 122.

1861, by the statement of the elder Hitchcock that such is the structure. Numerous sections across the range are given in which its anticlinal nature is brought out. Much evidence is adduced in the text pointing to the same conclusion based mainly on the occurence of a quartzite and conglomerate on both sides of the range associated with limestones. Edward Hitchcock, in 1847, had published sections which represented the range as an anticline slightly inverted by overturning towards the west. Adams, in 1845, had somewhat disconnectedly stated that the "granular quartz-rock" of the Taconic had an inverted dip,[1] but did not include in the Taconic rocks east of the quartz rock.

In all, the geology of Vermont (1861), contains twelve sections east and west across the State. Of these, eleven traverse the Green Mountain gneiss; the four southern ones show several synclines and anticlines in the gneiss; section V, one broad anticline; sections VI, VII, and VIII represent the anticline overturned to the west; and in sections IX, X, X^a, and XI the gneiss is given a simple anticlinal structure. On the west side of the range, in all sections except the fifth, the quartz rock is given an easterly dip of varying angle due to inversion. With one exception, at North Bennington, where the quartzite dips easterly at an angle of 5° to 20°, nearly in the position it was laid down, the writer has not seen an easterly dip in the rock along this belt as far north as Pittsford. The rock is usually quite massive and flinty, and bedding is not discernible. An easterly-dipping jointing is easily mistaken for stratification. Rocks immediately below have a lamination that dips easterly at a high angle, and the inversion argued is based largely upon observation on this structure; the coincidence of lamination and bedding along the western border has already been spoken of as the probable reason of the elder Hitchcock's accurate decipherment, in 1847, of the real altitude of the main axis of the mountains in Massachusetts. In 1868 the younger Hitchcock reiterated the interpretation

[1] First Annual Report on the Geology of Vermont, 1845, p. 61.

of his father, as to its anticlinal structure, and cites as proof the supposed equivalence of the "Potsdam" and "Levis" rocks on both sides of the range in Wallingford and Plymouth.[1]

THE PROBLEM OUTLINED.

From the opinions held as to the age, character, and structure of the Green Mountain axis just given, the main facts that stand out most prominently are that the centre of the mountains is occupied by strata to which the name gneiss is universally given, and that bordering this, on the west, occurs a terrane variously called "granular quartz," "quartz rock," and "quartzite," by different authors, together with an associated conglomerate. These last two rocks have been referred to various horizons from the Azoic to the Medina sandstone. Most geologists have grouped the central gneiss among the oldest, although Thompson considered it more recent than the Stockbridge limestone.

The relations of the conglomerate to the quartzite are by no means so simple as the older geologists were disposed to believe. Between the conglomerate and the quartzite there is an extensive series of metamorphosed sedimentary rocks which have been overlooked in the past, and which are in part the subject of this paper. Beneath the conglomerate horizon the gneisses and other rocks occurring in the amphitheatres, with their interstratified limestones and quartzites make a second series composed wholly or partly of sedimentary rocks separated from the first, of which the conglomerate is the base, by an unconformity sufficiently well identified to warrant a sub-division of the Pre-Cambrian Algonkian terranes into two series.

REASONS FOR REFERRING THESE ROCKS TO THE ALGONKIAN.

It is due to the labor of Mr. Walcott that the age of the quartzite on the western border of the range has finally been determined definitely. Upon palæontological evidence he refers it to the Lower Cambrian horizon and makes it equivalent to the red sand rock of Georgia, Vermont; the latter being an off-shore, and the former a near-shore deposit. In his Cambrian

[1] The Geology of Vermont, Proc. Amer. Assoc. 16th meeting, 1886, p. 121.

correlation paper[1] Mr. Walcott represents, probably hypothetically, the quartzite lying unconformably upon Pre-Cambrian (Algonkian) strata. The evidence for a time-break at Clarksburg Mountain in Massachusetts is undoubted, but farther north the relation of the quartzite to the subjacent rocks is much more obscure. As to the age of the subjacent terranes in Rutland County, Mr. Walcott refers them to the Archæan.[2] Since the Olenellus fauna, as determined in Vermont, delimits the base of the Cambrian horizon, all the sedimentary rocks below (adopting the classification of the U. S. Geological Survey) must be referred to the Algonkian. As mentioned above, the quartzite along the border is considered a near-shore deposit, and as such, it is evidence in itself of an approximate subjacent delimitation of the Cambrian sediments. On lithological grounds alone it would be correlated at once with the Potsdam on the eastern border of the Adirondacks, not thirty-five miles west of Wallingford, where the base of the Upper Cambrian is plainly seen resting unconformably upon the lower gneisses. The Potsdam is only faintly conglomeratic at the bottom, and the same is true of the quartzite in Vermont; so that in Vermont, at least, we are apparently without a true basal conglomerate in the Cambrian. The Lower Cambrian lies directly upon granitoid gneiss twenty-five miles south of Wallingford, where the contact is depositional with no conglomerate whatever. These occurrences indicate that we are not obliged to postulate still lower members of the Olenellus horizon on the ground that the base as there shown is not delimited by a conglomerate. In all the localities in Vermont examined by me a reversed dip in the quartzite on the west side of the range has not been observed; in the stratified series just below overturns occur along this line. This may be cited as evidence of discordance at the base of the Olenellus quartzite, as it is extremely unlikely that pronounced overturning could have taken place without involving the quartzite in its folds. That a thick

[1] Correlation Papers, Cambrian; Bulletin U. S. Geological Survey, 1890, Pl. II, theoretical cross-section at bottom of page.

[2] See Geologic column No. 8, opus. cit. p. 366.

bed of massive quartzite might not be affected by minor folds is recognized, as it is well known to be among the most resistent rocks. The series below, however, possesses quartzites still more massive and flinty, rocks which have been involved in close flexures as sharp as those in fissile associated beds. Through Massachusetts and southern Vermont the quartzite is remarkable for its persistence. The series immediately beneath is extremely variable in character and thickness due to original deposition and to the metamorphism that it has suffered. This series may be wanting, as on Clarksburg Mountain and at North Bennington, Vermont, where the quartzite lies unconformably upon crystalline gneisses.

In Walcott's hypothetical section across this continent, the Cambrian ocean is represented as sending a long arm up the Rutland Valley not covering the Green Mountains or the Adirondacks. Careful search through the Green Mountains proper has not resulted in finding any traces of the quartzite, there is no evidence that it once mantled over the range, although it is not unlikely that the Plymouth Valley was once occupied by Cambrian waters. There are abundant occurrences, however, of the lower series in the heart of the range, where many of the highest peaks are capped by one member or another. There is stratigraphical and microscopical evidence that this series has undergone repeated disturbances; the quartzite exhibits but one. This fact cannot be used legitimately as evidence of disparity in age, as it is probable that the thick bed of quartzite stood like a bulwark among more variable, less-resistant strata, not taking part in and not recording orographic movements unless of extreme intensity. It should not fail to be stated that in many localities the quartzite lies directly upon fissile mica schist, the upper member of the series below in apparent conformity therewith, and the difficulty of referring the schist to the Lower Cambrian or the Algonkian is apparent. I am disposed to believe it of the latter age and to make it the uppermost member of an upper series with the metamorphic conglomerate delimiting the series below. There are many reasons for this view, some of

which have been given. The limits of this paper will not permit anything like a full analysis of the evidence, which must be reserved for some future time. It seems generally, however, to be accepted that sedimentary rocks below the Olenellus horizon shall be considered to belong to the Algonkian. But few forms of the characteristic fauna of the Lower Cambrian are known to extend below this horizon; no fossils have been discovered in the big Cottonwood section in Utah, where 12,000 feet of silicious states and sandstone lie conformably below the olenellus zone. It is safe to assume that through such a vertical extent of rock the typical Olenellus fauna will not range, and consequently part at least must be placed with the Algonkian. That a part of the Vermont rocks immediately below the quartzite may be proven in the future to belong with the quartzite above is recognized, but the trend of the evidence collected by me points toward its classification in part at least with the Pre-Cambrian sedimentary rocks. Without commenting, the reasons for and against this view may be concisely stated, as follows: 1. Extreme diversity of the metamorphic series, or great lithological difference, as compared with the quartzite horizon. 2. Evidence of profound orographic movements in the latter not observed in the former, the folds often occuring overturned to the west. 3. Occurrence of the quartzite reposing discordantly upon granitoid gneiss not far south of the area under discussion and also near by in New York. 4. The near-shore character of the quartzite. 5. The fact that the quartzite does not occur in the heart of or to the east of the range, whereas the series below has been traced across the mountains. 6. In general, the converging of the gneiss-area shown on Hitchcock's map of the State[1] indicating a northerly-pitching anticline, and in detail shown in small flutings, while the quartzite does not exhibit this feature. 8. The occurrence of undoubted Algonkian rocks near by, south of Hoosac Mountain in Massachusetts identified by Mr. Emerson,[2] who finds Lower

[1] Geology of Vermont, 1861.

[2] See Geological Atlas of the United States, Hawley Sheet, 1892, B. K. EMERSON. Members of the Algonkian Period are briefly described on Sheet No. 4.

Cambrian conglomerate gneiss resting unconformably upon the upturned edges of a coarse gneiss associated with coarsely-crystalline limestone (Emerson's Hinsdale limestone). A line of Algonkian rocks extends southward from Hoosac Mountain (including the Stamford gneiss forming the core of the mountain) in a belt of oval areas across the Berkshire County Plateau. On lithological grounds these rocks would be correlated with some members of the Mount Holly series of Vermont to be described below. They may, however, be equivalent to the upper series of the Algonkian which has suffered less metamorphism to the north. The lack of fossil remains in the lower series cannot be used as evidence, since metamorphism has probably obliterated all traces of them. A disparity between induced structures in the two belts is also of no value as the quartzite has not recorded the regional cleavage owing to its massive character. Rocks stratigraphically above it, however, may have had the cleavage developed. The evidence against this delimitation is furnished by the apparently conformable mica schist, which, as a rule, accompanies the quartzite, and more locally other members of the series as well, which may have contained the Olenellus fauna. It must be left for future work to determine beyond dispute the relations of the series immediately below the Olenellus zone to the quartzite, whether the rocks are conformable or unconformable; if the former, whether the delimitation of the Lower Cambrian shall be placed above the mica schist or below it. Tentatively, the series just below the quartzite, the mica schist at the top and the conglomerate at the bottom, will be considered wholly or in part of Algonkian age. The separate members of this series with estimated thicknesses will now be described.

THE UPPER OR MENDON SERIES OF THE ALGONKIAN.

As far as known the best section of these rocks occurs in the town of Mendon, one mile north of Mendon village, on the west slope of Blue Ridge Mountain (Rutland Sheet). All the members identified occur here, although no single section thus

far examined has all the members developed characteristically or of maximum thickness. Each member thins out and thickens along its strike in the most remarkable manner. On Nickwacket Mountain, just north of the Rutland Sheet, for example, the pebbly, micaceous quartzite member attains its greatest thickness, and the pebbly limestone as well; while in the heart of the range, east of the Chittenden flats the lower quartzite-conglomerate horizon attains its maximum development. The mica schist is best seen along the Mendon section. Provisionally, therefore, for descriptive purposes the name Mendon Series will be given these rocks.

That the relations of the different members of this series could be worked out seemed for a time a hopeless task, as it was subject to such great variations in character, and was so intimately folded, but the order given below, from less disturbed localities is correct within narrow limits. The thickness of the different beds is estimated, such estimates being based upon great familiarity with them in widely-separated localities, and under various habits due to metamorphism. The estimates are well within the limits of maximum variation.

Beginning with the Olenellus quartzite which strikes N. 5 W. to N. 5° E., the next rock, as mentioned above, descending geologically, is a mica schist. It occurs along the west base of the hill, situated in the northwest corner of Mendon. Near the quartzite it appears conformable, but as one ascends the hill, going east, the rock becomes more crumpled; two hundred feet from the quartzite the stratification has been practically destroyed, while the regional schistosity, characteristic of the Appalachian range in New England, takes its place. This induced structure, along the borders of the range strikes quite uniformily N. 10° to 15° E., dipping commonly between 60° and 80° easterly, although westerly dips are noticed. The structure of the schist consists of minute plications and larger ones many feet across, closely folded and often overturned to west. Minute faulting along the axis of the crenulations has produced the schistosity (ausweisungschiefer) which has been

mistaken for the dip by the early workers in this region. A line drawn tangentially across the apices of the serratures shows the dip to be some 45° westerly in the upper (westerly) part. In this section the schist may be safely assumed to have a thickness of 800 feet. In some localities it is not over 50 feet thick, but just south of Chittenden village more than 1000 feet occur. All through the area the schist carries abundant lenses of secondary quartz introduced along the bedding and cleavage planes. These are considered genetically to be the excess of silica, resulting in great part from the decomposition of silicates originally in the rock, the alumina and potassium going to form the muscovite. Phases of the rock are without such lenses and are nearly free from quartz; other phases are largely quartz layers with thin folds of mica between. Some phases carry secondary feldspars, but they are exceptional. Under the microscope the normal constituents of the schist are seen to be a varying percentage of chlorite, a great deal of muscovite in slender, closely-packed plates and quartz in thin layers and scattered through the rock. Biotite in larger flakes is also universally present, with occasional feldspar grains.

Beneath the schist is the micaceous quartzite horizon, poorly represented in this section, but on Nickwacket Mountain having a thickness of 500 feet at least, and carrying several thin beds of crystalline limestone. Here there are not over 100 feet, with no interstratified limestone beds. It has scattered through it abundant pebbles of feldspar (microcline and orthoclase) besides quartz. The pebbles are small and have undoubted clastic outlines. Owing to their occurrence, this horizon is particularly easy to identify. Its strike is a little west of north, and the dip 80° easterly. Going east from the Olenellus quartzite the dips have grown continually steeper and now we find the rocks overturned to the west. This horizon presents many phases; traced south five miles it becomes a muscovitic schist, highly contorted, in which there is no evidence of detrital material; traced eastward towards the heart of the range, when caught in synclinal folds it is a granular, micaceous gneiss. Secondary feldspars

have been developed, but the larger clastic feldspar may be still detected in a fine-grained ground mass. On White Rock Mountain its place is occupied by a well-marked sandstone carrying some biotite. Microscopically the rock is made up essentially of small grains of clastic quartz. The larger pebbles of quartz and feldspar varying much in abundance in different localities. In the heart of the range a gneissose phase is produced by granulation and by development of pale-green, pleochroic muscovite and glassy plagioclase from the feldspar pebbles. The mica in the most massive phase is also green muscovite.

Immediately below the quartzite are fifty feet of pebbly, crystalline limestone, the pebbles being largely feldspar, like those in the quartzite. A narrow valley occurs here in this section due to the relatively rapid removal of the limestone. Nickwacket Mountain along its northern peak exhibits the best development of this rock, where its thickness may be safely estimated at 400 feet. It is only locally pebbly there in contact with quartzose layers or the main body of the quartzite above. Lack of persistence characterizes this work as one would expect. This seems to be due to want of, or to differences in, original deposition in many localities; to its alteration to other minerals; to its removal by solution, and to its being squeezed out during folding. The rock is locally graphitic and usually quartzose, especially where it occurs in thin beds in the micaceous pebble-bearing quartzite. Phlogopite is common in little flakes in some dolomitic varieties. All through the mountains of the Rutland Sheet it forms an easily-recognized horizon. Near the summit of Pico peak, just north of Killington, it occurs, and by its rapid removal it has given rise to escarpments on the southwest slope of the mountain.

Some fifty feet of green muscovite schist occurs next below, which may be considered a laminated phase of the micaceous quartzite which usually appears below the limestone. This grades downward into a flinty quartzite along this section. Locally the quartzite carries pebbles of quartz and as one goes east it is seen to grade into the metamorphic conglomerate that

has become so classic through the contributions of the elder Hitchcock. This horizon is one of extreme variability and no one name can be given it that will have anything like a general descriptive application. Further south Mr. Wolff has described it as a conglomerate-schist,[1] but there the percentage of feldspar, both secondary and original is large and the rock has a marked schistosity. Another phase from the Mendon section is a well-developed conglomerate in which the pebbles vary in size from a pea up to small boulders. The larger ones are nearly all of vitreous quartz, many of a fine blue color. At East Clarendon nearly all detrital material is obliterated by the shearing action that has developed the perfect lamination observed there. Exposed south of Mendon village this horizon is a vitreous massive quartzite, probably 500 feet thick, devoid of all evidence of stratification. Three miles south of there, the quartzite has disappeared and a well-laminated muscovitic gneiss, similar to that occuring at East Clarendon and Bald Mountain east of Rutland, takes its place. One mile north of Chittenden a remarkable phase occurs; the rock as a whole is still a vitreous quartzite, but it is made up almost entirely of angular and rounded boulder-like areas of the same material. The boulders seem to represent in part an original conglomerate. If boulders of a composite nature were deposited with those of quartz, the silicates have been converted into what little ground-mass the rock now possesses. After the rock was cemented into a vitreous quartzite, brecciation took place, and today we see a mixture of genuine boulders, some having a diameter of several feet, and pseudo-boulders of larger dimensions, some angular and others having rounded outlines. imitating genuine clastics. The former are identified by their occasional occurrence in a matrix or cement that has protected them from distortion or granulation. East of Chittenden flats an even greater development of quartzite occurs where its thick-

[1] Metamorphism of Clastic Feldspar in Conglomerate Schist, Bull. Museum Comp. Zoöl. Whole series Vol. XVI., No. 10, Plate II, shows two excellent microphotographs of this phase of the conglomerate where the clastic material is nearly obliterated.

ness is not less than 700 feet. Where an excess of shearing motion has operated, a well-laminated schist has resulted, examples of which may be seen at the base of the conglomerate in the Mendon section and extending north and south from there; on the summits of Pico, Killington, Mendon, Little Killington, and Blue Ridge Mountains, and in countless other localities.

Many phases of this schist occur characterized by accessories such as chlorite, biotite, and magnetite. An important and wide-spread variety carries ottrelite in prisms and radiating bundles.[1] Muscovite predominates over other micaceous minerals, both colorless and green varieties occurring, while feldspar is only sparingly present. All the varieties of this horizon occur in great confusion, grading into one another vertically and along the strike. In my notes the most schistose variety has been called Killington schist, and this with the green gneissose phase are the two most common occurrences of the rock. It seems preferable to adopt the name conglomerate-gneiss for this horizon as it is descriptive of its present mineral constitution and suggestive of its past history. All the evidences of profound dynamic movement observed in this series are observable in the quartzite along the Mendon section. In fact, no rock in the Mendon series bears evidence of so great disturbances.

Considering 350 feet to represent the thickness of the quartzite and conglomerate at this point, the total thickness of the section is approximately 1,300 feet. It is probable that in some localities there may be 2,000 feet of strata, and in the northern part of the State no doubt the formation is much more greatly developed. As a whole it is subject to great variations in thickness, and may decrease to two or three hundred feet, as on the south end of Bear Mountains in Wallingford. The relations of the conglomerate-gneiss horizon to the underlying rocks will be

[1] This phase was described by the writer in the American Journal of Science, Vol. XLIV., Oct., 1892.—An Ottrelite-Bearing Phase of a Metamorphic Conglomerate in the Green Mountains.

considered after a general description of the rocks comprising the second or lower division of the Algonkian terranes has been given.

THE LOWER OR MOUNT HOLLY SERIES OF THE ALGONKIAN.

In the amphitheatre already described, the rocks of this series occur well-developed in the towns of Mount Holly and Shrewsbury and extend south probably to near the Massachusetts line. They are perhaps no more characteristically developed in Mount Holly than elsewhere to the south, or possibly to the north, but they are best known to me there of anywhere in the State. It seems best, therefore, to designate the rocks of this central area, or core of the Green Mountains, the Mount Holly series.

In nearly every way the core rocks are contrasted with the Mendon series; these differences will be emphasized below when the question of the relations of the two series will be discussed. A description of the different consecutive members of the series cannot be given, as the rocks are too variable in character, and dynamic action has involved them in such complications. No approach has been made in the determination of the order of their occurences, and it is doubtful if such a sequence will be made for years to come, unless more discriminating criteria are forthcoming. Many unlike members there are, but they are characterized by no presistence of horizon, or if they are, metamorphism has obliterated all distinguishing features. The area appears as a multitude of patches of different kinds of rocks, whose relations with one another seem impossible of solution. Unlike the Mendon series, there is no pronounced northerly lamination agreeing in the main with the genuine strike of the stratification. The structure here is in part due to zones of unlike mineralogical composition; most of the igneous rocks have been well laminated and the gneisses and schists have their characteristic arrangement of constituent minerals.

A detailed description of all the varieties of rock occurring will not be attempted here; some of the more noteworthy areas will be

briefly mentioned. Along the south slope of a hill just south of Mechanicsville, a section is exposed showing fine-grained biotite gneiss at the base, passing imperceptibly into a sugared quartzite above. This in turn is overlain by coarse saccharoidal limestone; and a muscovitic, garnetiferous schist overlies this, capping the summit of the hill. These rocks strike in general east and west and dip northerly. A section on the southwest slope of Ludlow Mountain, two miles southeast of here, exhibits at least two beds of coarse limestone grading into tremolite and green hornblende, interstratified with layers of schist. These rocks strike west of north and dip easterly. On the southwest slope of Saltash Mountain a bed of tremolitic limestone interstratified in biotitic gneiss trends northwest. At Northam village, a similar coarse limestone occurs associated with a vitreous quartzite, a laminated eruptive rock and a rusty muscovitic schist. All through the core there are patches of these coarse limestones in a great variety of association, such as with coarse augen-gneisses (a common occurrence), quartzites, schists, and other rocks. Fine-grained, blue marbles are present in two or three localities. In all cases the limestones are in irregular lenses, and are extremely local; their occurrence with coarse gneiss affords no evidence of structure; these scattered, irregular outcroppings and differences of association make them impossible of correlation. There may be two horizons of limestone in the core or there may be a dozen. The same is true of the quartzites and other sedimentary rocks. Limestone belts are, however, frequently identified by their metamorphosed equivalent, tremolite, or in rare instances, serpentine replaces the limestone. The Mount Holly series has scattered all through it these undoubted areas of sedimentary rocks recognizable where from manifold causes they have escaped destruction or metamorphism, and their clastic characters have not been obliterated. They probably represent remnants of a once great sedimentary series older than the Mendon series.

The rocks associated with the evident clastics present a great variety of texture and mineral composition. Thin sections show, however, that the differences are mainly due to variations

in grouping of the component minerals rather than to differences of composition. Gneisses are most common, occurring as fine-grained, chloritic rocks or coarse biotite, augen-gneisses. A brownish coarse gneiss with porphyritic crystals of orthoclase extends in intermittent outcrops from Wilcox Hill on the north to Button Hill on the south, a distance of eight miles. This rock carries both biotite and muscovite, the latter evidently derived from the feldspar. In Eastham, Northam, and east of Bear Mountain, there are areas of coarse biotite gneiss with interstratified beds of quartzite and limestone. Fine-grained, chloritic schists and gneisses are abundant, as on the summit of Saltash Mountain.

The area immediately about Mount Holly village on the Central Vermont Railroad, is characterized by a great number of amphibolites. These occur as schists, either intrusive or extrusive, and as dikes, cutting one another, and the country rock. They occur interlaminated with various rocks—quartzites, gneisses and schists, and possess the local schistosity of the enclosing rock. This is as true of the dikes as of the sills, affording a conception of how far removed from any key to the real stratification is the lamination of these rocks and how faulty geological interpretation must be when deciphered on the basis of induced structures. Aside from the interest one naturally feels in eruptives as old as these, their importance as evidence in separating the Mendon from the Mount Holly series cannot be overestimated. Modern basic dikes of camptonite and other igneous rocks traverse the core rocks, but they are younger than the last disturbance of the Green Mountains, cutting Algonkian and Cambrian rocks alike.

Following the accepted definition of the Algonkian rocks, this lower series as well as the upper must be grouped as Algonkian. Although possessing many rocks undoubtedly igneous, and others whose origin is problematical, there is a considerable development of genuine sedimentary rocks, warranting us to place the whole series among the Algonkian. The evidence for this sub-division, which is based upon manifold differences between

the Mendon and Mount Holly series and their associated phenomena, will now be considered.

EVIDENCE OF DISCORDANCE BETWEEN THE MOUNT HOLLY AND MENDON SERIES.

Lithological differences.—These are many, and furnish important data for the classification of the two series into two divisions. A hasty description has already been given of the upper series and a still more imperfect one of the series below, which, owing to its vast variety of rock phase, hardly warrants a detailed description of each rock. In a large way it may be said that the upper series is prevailingly schistose; the lower prevailingly gneissic. The rocks of the upper series can all be referred indisputably to a sedimentary origin; part, at least, of the lower are of igneous origin, and a still larger part afford no criteria which will enable us to assert their origin. Coarsely crystalline limestones occurring in the core have in no case been detected in the upper rock, and pebbly limestones or quartzites are never met with in the Mount Holly series. Along the western border of the range, from Sunderland to Chittenden, none of the core rocks are seen interstratified with the Mendon series. An association sometimes occurs, but only when there is evidence for a faulted relationship. In the amphitheatre, where the lowest rocks occur, none of the upper series have been found. Farther north the lower terrane makes up but a small part of the surface rocks; the Mendon series capping all the prominent mountains as far north as Nickwacket Peak. The chaotic occurrence and lack of discoverable sequence in the core rocks find no parallel in the relatively persistent and orderly arrangement of the upper series. To the eye the core rocks have an older look; they are commonly loose-textured when weathered, crumbling often in the hand. Under the microscope, the cause for this is readily seen in the universal granulation that the rocks have suffered, a phenomenon strongly in contrast to the more coherent, less-sugared rocks of the border. Other differences in the two series are found in their mineralogical composition as a whole. Such differences

may well be due to unlike environment making deductions in favor of unconformity to a certain extent misleading, but the contrasts noticed are too strongly marked to admit of dispute as to cause.

The gneisses and schists of the older rocks are characterized by a wide-spread development. Colorless muscovite, chlorite, orthoclase, biotite, and quartz occur as essential constituents; epidote, zoisite, titanite, and garnets occur as accessories. Of these, the first four minerals occur much more sparingly in the upper series; the last three are not remembered to occur at all. Phases of the lower limestones carry tremolite or serpentine, while dark hornblende occurs in abundance. Orthoclase is relatively much less abundant in the border rocks where it occurs frequently as pebbles. Pale-green, pleochroic muscovite, secondary plagioclase, magnetite, and ottrelite, so common in the upper series, are much less abundant in the lower series; green-muscovite and ottrelite are not known to me in the central area. The limestones of the two belts may also differ as to the percentage of carbonate of magnesium present. No investigation of this subject has been attempted.

Reference has already been made to the metamorphosed basic igneous rocks, amphibolites, of the central area. One of the best sections of these rocks is displayed in the railroad-cut at Summit station, where they are exposed for nearly half a mile. Numerous separate members can still be distinguished in the mass by textural variations. They are cut by dikes of the same material and also by more modern dikes of camptonite. Such a series of amphibolites probably represents a period of volcanic activity, antedating the Cambrian, of great areal extent. Nearly everywhere, where these lower rocks are exposed, amphibolites are present also. To the north they occur only in scattered patches associated with granitoid gneiss; to the south reconnaissance work has not detected them, but they probably occur there. Mr. Wolff has described an amphibolite from a hill situated about one mile south of Mount Holly station, and he refers

it with probability to an original diabase.[1] Remains of an original bisilicate (augite) can still be found in the rocks. Whether diabase or basalt their occurrence in sheets traversed by dikes of the same material and their great abundance lead me to consider them surface flows or intrusives. Their abundance may be cited as evidence of extrusive origin since it is extremely unlikely that any area, reasoning from analogy, would be traversed by so large a number of intrusives. This view is also sustained by the fact that diabases and basalts are prevailing surface flows. Such regions as the Triassic (Newark) of the eastern United States, Keweenaw Point, the western plateau, and the Deccan being examples. Their restriction to the Mount Holly series not only points to their extrusive origin, but whatever their origin they afford almost positive evidence of an unconformity at the top of the series; if intrusive, we should naturally expect to find them occurring in the Mendon series, which is not the case; if extrusive, their occurrence only in the core rocks is even more in favor of the proposed subdivision. As to the importance of the evidence afforded by these rocks no better confirmation can be found than the following from Van Hise.[1] "Eruptive rocks are often an important guide in determining structural discordances. These are valuable when the older series has passed through an epoch of eruptive activity before the newer series was deposited. In such cases, bosses, contemporaneous or intrusive beds, volcanic fragmental material or dikes may occur in the older series which nowhere are associated with the newer. It is possible, of course, that eruptives may penetrate the inferior members of a series and never reach the higher formations; but if it is found that the supposed inferior series is associated with abundant material of igneous origin which never passes beyond a certain line, it is almost demonstrative evidence of the later age of the newer series."

[1] Geology of the Green Mountains in Massachusetts, by R. Pumpelly, J. E. Wolff, T. Nelson Dale, and Bayard T. Putnam, Monograph U. S. Geol. Survey, Part 3, submitted in 1889.

[1] Correlation Papers—Archæan and Algonkian, Bull. No. 86, U. S. Geol. Survey, p. 520.

Structural differences.— Evidence afforded by a study of the structure in the two series, both original and induced, has an important bearing upon the separation of the two terranes. Of first importance may be mentioned the relatively orderly strike of the lamination and bedding of the upper series in comparison with the strike and disordered succes-

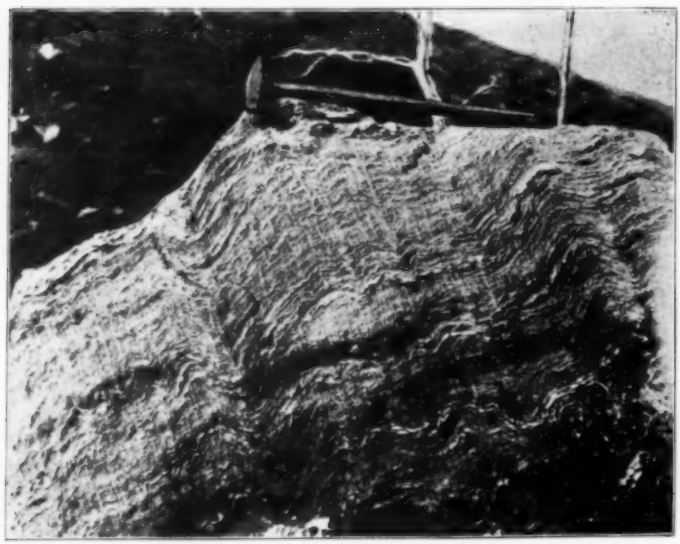

FIG. 1. Initial development of strain-slip cleavage, dipping to the right in a schistose phase of the conglomerate-gneiss horizon. The fluted bedding planes are seen dipping to the left. Under the microscope the faulting of the sharp crenulations is plainly visible with secondary formation of muscovite along slipping planes.

sion of the core rocks. The Mendon series in many localities is flexed into minute puckerings and minor folds having northerly pitching axes overturned to the west. Along the western line of the folds, and in synclinal troughs, sharp crenulations are developed; on the backs of folds stretching and consequent schistosity are best shown. When the sides of the crenulations are forced to move over each other strain-slip clear-

age is produced. A beautiful example of this is seen in Fig. 1, from the schist phase of the conglomerate gneiss two miles north-east of East Clarendon, near its contact with a coarse underlying gneiss. Blue Ridge and Pico Mountains are now capped by schist produced upon the back of folds. Close folding with axes striking nearly north and south only occurs in the amphitheatre near the summit of the greatest elevations, as on Mount Holly—a hill about a mile south of the station by that name—and near the contact with the Mendon series. The rocks of the core have no presistent strike and dip, neither of schistosity nor bedding; east and west strikes are as numerous as those trending north and south and the dips are as variable. Throughout the core the gnarled and tortuous folding of the strata represents the effect produced by the operation of repeated periods of mountain-building action of enormous force, directed not always from the east and west as in the Mendon series, but from the north and south as well.

A careful study of the Mendon series recognizes but two periods of orographic disturbance, the second acting along approximately the same lines as the first. This is well-indicated under the microscope, and in the field it is beautifully shown at North Sherburne where the strike of the rock (a conglomerate) is N. 25° W.—a trend produced by the first period of folding. The schistosity of the Green Mountains traverses this obliquely, making an angle of 35°–40°, striking N. 10° to 15° E. Both structures dip easterly at a variable angle. Forces that induced the regional lamination of the range could not have produced the great variety of trend observed in the folding of the Mount Holly series. The question of difference of environment of the central or lower parts of anticlines as compared with the outer must not be overlooked. All the phenomena go to show that the superior or Mendon series was above the neutral zone and that great slipping, stretching and crumpling took place therein dependent upon position in this belt. Below the neutral zone during the folding of the Mendon series undoubtedly most of the core rocks were placed where crushing would largely

exceed shearing and the development of the regional schistosity would not be expected. It is nevertheless true that the core rocks, although as a whole more massive than the border series, have in most localities a pronounced lamination not always due to the formation of micas, as in the Mendon series, but frequently the result of a rearrangement of the chemical combinations of the rock brought about by metasomatic and dynamic agencies. This is shown by the formation of amphibolites from some basic eruptive rock and by banding produced by the parallel injection of pegmatitic veins along the schistosity. If the core rocks were below the neutral zone during the folding that induced the regional clearage in the border series, then manifestly the intricate flexing of the inferior rocks was developed before the deposition of the Mendon series; if the core rocks were above the neutral belt they should have the normal lamination and characteristic folding universally occurring in the upper series, which is not the case.

A coarse granitoid gneiss and some associated quartzose sedimentaries occurring at North Sherburne are characterized by hundreds of minute faults to the square foot, having most divergent trends. That this was an area below the zone of neutral motion, thus permitting compensation by faulting or crushing is not tenable since the rocks are not more than 300 feet below a metamorphosed conglomerate, in which no faulting of this nature has taken place. In this phenomena we have more evidence pointing to the conclusion that the core rocks have undergone many mutations not participated in by the overlying Mendon series and must therefore be separated by an uncon formity.

The conglomerate-gneiss horizon. — On the west side of the range, the Hitchcocks have colored in this horizon extending in scattered patches beneath the "quartz-rock" from Sunderland on the south to the Canadian boundary, thickening toward the north. A patch is shown at Sunderland and another at Wallingford. Beginning in the town of Ripton, if this interpretation be correct, it extends continuously across

the State. Between the areas indicated upon their map,[1] the writer has observed it or its metamorphosed equivalent, so it is known to extend in an unbroken line from near North Bennington the entire length of the State as a persistent characteristic horizon. At the Massachusetts line it is wanting where the Olenellus quartzite reposes discordantly upon a granitoid gneiss. On the east side of the range it is described by the above-mentioned authors as occurring in a narrow band running across the towns of Plymouth and Ludlow, and is correlated with the conglomerate horizon of the Rutland Valley. It is largely upon this eastern occurrence of the conglomerate that the anticlinal nature of the Green Mountains was hypothecated by them. The phenomena of stretching of quartz and gniess pebbles in this horizon and their destruction thereby, furnished the elder Hitchcock with the necessary confirmatory data for his then revolutionary ideas concerning the production of gneisses from conglomerates by metamorphism. About one mile north of Tyson's Furnace in Plymouth and on the south slope of Bear Mountain in Wallingford occur the now classical localities where the conglomerate was most carefully studied by him and where nearly all his illustrations were obtained. It is doubtful if two areas can be found in metamorphic regions where the change of sedimentary rocks to crystalline gneiss is better or more satisfactorily shown. It was with fear and hesitancy that the question of this new effect of metamorphism was discussed, but the carefully-elaborated arguments advanced show that a keen appreciation of the proper interpretation of the phenomena revealed there was felt by the author of this most valuable contribution to the science of geology.

The first area described (the Wallingford locality[2]) is situated about where the 1500 feet contour makes a sudden jog to the south. Here the elongation and flattening of the pebbles, their contorted character and the transition of the rock to gneiss are remarked upon.

[1] Opus. cit. Pl. I., Vol. II.

[2] Opus. cit., Vol. I., pp. 32 to 44.

In Rhode Island the Newport conglomerate with its indented and elongated pebbles was a starting point in the series of changes from an unchanged conglomerate to a gneiss, the Wallingford conglomerate being an intermediate stage of metamorphism, while the Plymouth occurrence represented the completed alteration.

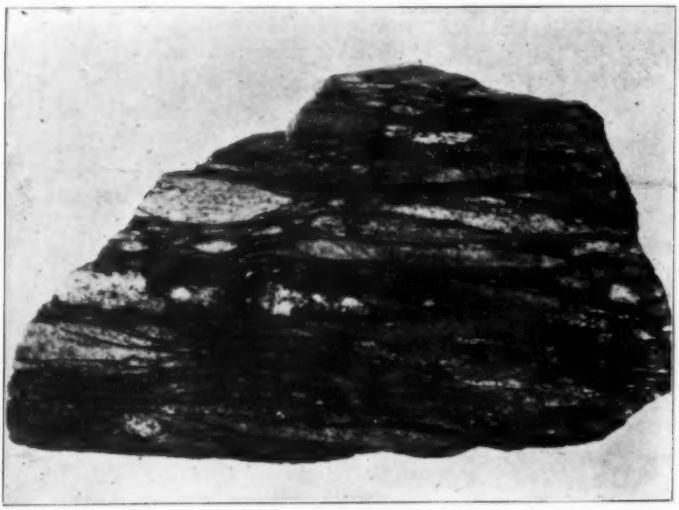

FIG. 2. Longitudinal cross-section of stretched conglomerate-gneiss. The pebbles in the upper half of the figure are mainly gneiss. In the longest pebble near the center the original lamination can still be made out. The more feldspathic clastics are now seen as thin linear films of crushed quartz and feldspar between more resistant pebbles of quartz and quartzose gneiss. From Edward Hitchcock's Green Mountain locality, one mile north of Tyson's Furnace, Plymouth, Vt. Size of block photographed 13 x 8 inches.

Much more interest was felt in this last-discovered locality where gneissic and quartz pebbles are flattened and pulled out into alternating, non-persistent bands of these minerals in a highly sugared condition, but still clearly possessing their deformed clastic outlines. Although not directly pertinent to the subject of this paper, it seems desirable to reproduce here a photograph of a block of this conglomerate, cut in longitudinal cross-sec-

tions, now in the geological exhibit of the Agassiz Museum, Cambridge, Massachusetts, Fig. 2. A fair percentage of the pebbles are of a composite nature (gneiss) and as would be expected, they have yielded most easily to the deforming forces. They now form in large part with secondarily-developed green muscovite, feldspars and cement of the pebbles, the more schistose folia of the rock. Stretching and flattening have resulted from a force operating along the plane of bedding in the direction of dip. The pebbles have been elongated most in an east and west direction, and their perceptible flattening indicates that this elongation took place under enormous load ; an environment unlike that of the pebbles at South Chittenden, which have undergone elongation without marked lateral yielding. The environment factors here were probably extreme load, a force tending to push the rock as a whole towards the west, and the presence of water charged with inorganic compounds that promoted the alteration of the clastic feldspar material, already weakened by sub-aërial decay to more stable compounds under the changed environment, and at the same time cementing the mosaic of quartz and feldspar grains resulting from the enforced granulation into a coherent rock. It seems unnecessary to postulate a high degree of temperature to account for these phenomena ; nor has plasticity, as properly defined, played any part in the deformation of the quartz and gneissic pebbles.

At North Sherburne a conglomerate occurs of considerable thickness and extends south to Ludlow, a distance of twenty-five miles. It is fully as persistent on the east side of the range in the area under discussion, as on the western, and, although some phases are unlike the western belt as a whole, it may be safely correlated with the conglomerate-gneiss horizon making, as first suggested by Adams, an anticlinal axis between Plymouth and Rutland valleys.

The question of the relations of the conglomerate-gneiss to the lower or Mount Holly rocks, has been most carefully studied on the western side of the range where the country is more open. At East Clarendon ; just north of South Chittenden, and at Hitch-

cock's Bear-Mountain locality, are three of the most instructive sections, where the contact relations of the two series are shown. All these sections show the relations of the two series in apparent *structural* conformity brought about by dynamic movements exercised throughout the rocks as a whole, but having a maximum obliterative effect immediately at the base of the conglomerate, since at this point the underlying rocks were best conditioned to record such action. Speaking of the transitional beds on Hoosac Mountain, between the Lower Cambrian quartzite-conglomerate horizon and the granitoid gneiss, Mr. Pumpelly writes as follows:[1] "This unabraded zone of crystalline rock," (reference is made here to the zone of semi-disintegrated rock on which the conglomerate was deposited unconformably) "which had its rigidity weakened by beginning disintegration, would, under folding, pressure, and metamorphism, show on the one hand a perfect and true transition into the parent crystalline rock, and on the other hand pass into the much younger beds through the similarity of the constituents derived from it; and an apparent conformity would be forced upon the whole series, and the time break would be masked by the foliation induced by the shearing action due to a slipping movement." An interpretation which so satisfactorily accounted for the transition obtaining on Hoosac Mountain can be as well applied to the transitions in Vermont at the base of the conglomerate, only here the terranes below are of a very variable character, and in a great part were already possessed of a gneissic habit which by rearrangement would even more readily take on the lamination of the rocks above. Wherever the conglomerate gneiss is found on the west side of the range a perfect transition to the lower rocks always exists, and all evidence of a discordance, such as obtains in more modern rocks of necessity must have been obliterated. It is thus seen that criteria applicable for the detection of more recent time-breaks have but little value where the rocks have been subjected to such powerful and repeated orographic disturbances,

[1] The Relation of Secular Rock-Disintegration to Certain Transitional Crystalline Schists, R. Pumpelly, Bull. Geol. Soc. of America, Vol. II., p. 215.

unless the conglomerate itself be taken as sufficient proof of an unconformity.

A practical difficulty was first met in finding a source for the abundant pebbles of blue quartz which occur so plentifully in the rock, and although sources for them are known, the proportion of such material seems to bear no proper relation to the known extent of rocks in the Mount Holly series that would be likely to yield pebbles of this mineral. Reference has already been made to a coarse phase of the conglomerate near South Chittendon where its clastic quartz best deserves the name of boulders. Such coarse phases are exceptional. An unusually coarse variety occurs one mile north of Mendon village. With the quartz pebbles there is a plentiful sprinkling of gneiss pebbles, varying in size from small grains up to two feet in diameter. Clastic areas of orthoclase are also numerous; pebbles two inches in diameter being the largest. Under the microscope abundant small grains of detrital feldspar can be detected. At this locality the original character of the rocks seems best preserved of anywhere that it is known to me, and a careful comparison of its gneissic clastics with the gneisses of the lower series immediately subjacent was made in hopes of being able to refer the pebbles to their sources. Macroscopically there appears to be no doubt that most of the pebbles were derived from the complex of gneisses to the east, and in the days before microscopical methods were used such a source would have been unhesitatingly affirmed. But today the microscope instead of simplifying one's difficulties apparently only adds to them. It is seen that the conglomerate here has recorded the evidence of dynamic action to a somewhat less extent than in many localities, but still an evident effect of metamorphism is observed. The micro-study of the lower gneiss shows them to be coarse to fine, irregularly-laminated orthoclase rocks in which both quartz and feldspar are badly crushed and distorted. About the resulting mosaics have been developed abundant epidote and titanite crystals and patches of biotite, colorless muscovite and chlorite. In the clastic gneiss little or no epidote or titanite can be detected, while there is always present more or less pale-green

pleochroic muscovite, that characterizes the conglomerate-gneiss horizon and give to it its greenish color, the result of alteration of a potassium feldspar during dynamic movement. Its other constituents seem to be identical with the neighboring gneisses, but on so slim a basis it is not deemed safe to refer the clastics to any particular gneiss area in the Mount Holly series. The feldspar clastics appear to have been derived from the pegmatite veins that are very abundant in the lower rocks to the east.

The Bear Mountain locality in some respects is more important in its bearing on the question of non-conformity than the one above described; no one area furnishes the data for all the conclusions to be drawn from the horizon. Attention was first called to the abundance of small clastic pebbles of feldspar occurring there, by Edward Hitchcock in 1861,[1] and in 1891, by Mr. Wolff.[2] As remarked by Mr. Pumpelly,[3] there seems to be "no other source than the débris of the deeply decayed Mantle" on which the conglomerate was lain down, and as such they point to a land surface close at hand where sub-aëreal decay had weakened the cohesion of the rocks, permitting a positive movement of the sea to build the more superficial mantle containing the feldspar grains, and a lower semi-disintegrated zone of gneiss and loosened blocks of gneiss into a conglomerate. The phenomenon of false bedding is well shown here, and was figured by Hitchcock[4]; transitions from coarse sediments, when the pebbles of quartz attain a diameter of nearly a foot, to fine material, point to the ordinary conditions obtaining along our coast. So, too, the outlines of the clastics are those that are characteristically produced by wave action, unless deformation has taken place, which is usually the case at this locality. All these facts are subordinate in their value compared to the conclusion to be drawn from the conglomerate-gneiss horizon as a whole, extending as it does across the State of Vermont, and presenting in one

[1] Opus. cit. p. 34.

[2] Metamorphism of Clastic Feldspar in Conglomerate Schist. Bull. Comp. Zoöl., Vol. XVI., pp. 173 to 183.

[3] Opus. cit., p. 211.

[4] Opus. cit., p. 32.

place or another all the eminent characteristics of a basal conglomerate.

An apology may be in order for dwelling so long upon the evidence detailed in support of the conclusion that an unconformity occurs at the base of the conglomerate, when, to many, the evidence afforded by the conglomerate alone would he considered amply sufficient; but in an area so greatly disturbed and metamorphosed as this, it seems best to enumerate all possible criteria that can be legitimately advanced tending to sustain the above conclusion.

SUMMARY.

To summarize briefly, this paper is hoped to have substantiated essentially the following facts:

1. That immediately beneath the Lower Cambrian quartzite in Vermont there is a series of more or less metamorphosed clastic rocks of no inconsiderable thickness; the upper member of this series being a dark chloritic mica schist; the lower member a highly metamorphosed conglomerate, and between these several pebbly limestones and pebbly micaceous quartzite strata. Evidence for and against an unconformity at the top of the schist is presented, but no satisfactory data are advanced to sustain either interpretation. The evidence for a time-break at the base of the conglomerate is thought to have been established, and the data in support of this conclusion are discussed in some detail. These rocks are referred to the Algonkian Period and are provisionally called the Mendon series.

2. That below the Mendon sedimentary rocks, a still older, more metamorphosed and more variable series of stratified rocks of Algonkian age occurs, together with gneisses and schists, whose origin is unknown, and abundant metamorphic equivalents of old basic igneous rocks. Many of the varieties of rocks occurring in this series are enumerated, and, together with their structure are contrasted with the rocks of the Mendon series, whose basal member, the conglomerate, delimits the series above. From their typical development in the town of Mount Holly, Vt., it is suggested that these rocks be called the Mount Holly Series.

CHARLES LIVY WHITTLE.

EDITORIALS.

THE protracted ill health of Major J. W. Powell has led to his resignation of the office of Director of the United States Geological Survey, and to appointment, with his hearty endorsement, of Professor Charles D. Walcott who has had charge of much of the executive work of the Survey for the past year or more. Although Major Powell has suffered much from other forms of ill health for several years, the immediate cause of his resignation, we understand, was a renewal of trouble from his amputated arm, which had reached a stage requiring re-amputation. As is well known, Major Powell lost his right arm on the evening of the first day of battle at Shiloh, while he was gallantly trying to hold his battery's position till night should come to the relief of the sorely pressed army. We are glad to learn that the re-amputation has already been successfully performed, and that there is every prospect of a speedy recovery. The probability of a measurable restoration to health has been regarded sufficient to warrant Major Powell in retaining the less exacting directorship of the Bureau of Ethnology, and to give encouragement that he may be able to finish the important ethnological studies upon which he has been engaged for several years. It is earnestly to be hoped that this may be realized, and that he may be permitted to add to his record as an executive the more distinctively scientific fruits of a very original and philosophical mind.

The appointment of Mr. Walcott meets with the hearty concurrence of his associates, and will be approved, we are sure, by scientific men generally. Though a comparatively young man, he has shown both investigative and executive ability of an unusual order and possesses in high degree the personal qualities which the position requires.

Major Powell's administration has been a very notable one, and will doubtless stand forth even more distinctively as we recede from it in time and see it in perspective when its greater outlines will be better defined and its details will fall into their places as parts of the whole. From a comparatively small corps of workers, with an inadequate appropriation, trammeled by legislative restrictions and uncertainties, and embarrassed by untoward inheritances from three inharmonious territorial surveys, the organization has grown to be perhaps the largest and most productive of official geological surveys. Its very strength has indeed been an occasion of criticism on the part of some who have conceived themselves to be unfavorably affected by its great influence.

One of the most notable characteristics of the administration has been the large consideration given to the differentiation of investigative work. To a degree perhaps never before equaled in governmental work facilities have been afforded for the careful and broad investigation of special subjects of a fundamental nature. A portion of the results of these studies have appeared in the special papers of the annual reports, in the monographs, and in the correlation papers, but a considerable portion are yet to be issued.

Externally, perhaps the most conspicuous feature of Major Powell's administration has been the great prominence given to topographic work. If this work be conceived as subserving no other function than that to which topographic maps were usually put previous to the current decade, it might well be doubted whether so large a proportion of the resources at the command of the Survey were wisely given to this part of the work, and the question of ratio and proportion may be a pertinent one in any case, but it is necessary to a proper interpretation of the polity of the Survey to note that an important evolution of geological science has been in progress, and that topographic and physiographic factors now play a part in good geological work that they have never played before. Physiographic geology has had a new birth, and has taken an important place among the

essential branches of the science. Major Powell has himself, as an individual investigator, been one of the pioneers in this new departure, and the doctrine of the base-level, which we owe so largely to him, taken with its corollaries, constitutes one of the most important contributions of recent decades. In so far as the topographic work of the Survey has become an adjunct and antecedent of the new physiographic phases of geology, it merits the highest commendation. In so far as it has fallen short of this, it perhaps expresses the practical difficulty of at once rendering topographical work *geological*, a difficulty not to be wondered at since topographical work has been so largely regarded as a function of some other science than geology, some science in which the mere hypsometrical factors of relief, mechanically represented, have been chiefly considered instead of the genetic factors that give meaning to the topography. Until a generation of *geological* topographers can be trained up, topographic work cannot be expected to be other than mechanical and relatively expressionless. It may be questioned whether some of the topographic effort that has taken the *extensional* form might not better have taken an *intensive* form in the interest of transmuting mechanical topography into geological topography, or, in other words, the substitution of genetic expression for meaningless mechanicalism. But, withal, the great development of the topographical side of the Survey has been in the line of progress and the needed transformation in the fundamental nature of the work should grow out of it through persistence in the educative process already begun. We have no sympathy with the geologist who looks upon topographic work as an alien function to be performed by those whose profession does not lead them to know how topographic relief was produced or what it means, and who carps at the Survey for an alleged invasion of fields outside its domain.

Under Major Powell's administration, the physical and philosophical phases of the Survey have received a more marked impetus than the palæontological, though an able and active corps of palæontologists have always formed a large division of the

staff, and have made most important contributions. This ratio of development has been, perhaps, duly proportionate to the demands of the growing science, for the palæontological side of the governmental work was previously, we think, the more advanced and occupied a relatively larger part, and might well advance less rapidly and permit the physical wing to come abreast of it.

The administration has had a good degree of success in the very delicate and difficult task of coördinating the work of the general government with that of the states and in securing friendly and helpful coöperation. Very notably excellent results are being worked out by the joint effort in some cases.

Not to unduly lengthen this notice by dwelling upon other salient features of Major Powell's administration, suffice it to say that it has been marked by originality and boldness of conception, by good judgment in organization, by unusual skill in securing favorable legislative action, by large liberty to colleagues in the prosecution of their work and the publication of their results, by broad and comprehensive views of the functions of the Survey, and by great courage and tenacity of purpose in the endeavor to compass them.

The administration goes into the hands of a chosen colleague in whom the retiring Director will find a worthy successor. We predict for Mr. Walcott a brilliant administration. T. C. C.

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We very much regret that the difficulties connected with the Missouri Geological Survey, to which we have once before made allusion, culminated recently in the abrupt termination of Mr. Winslow's directorship. This unfortunate result finds some mitigation, however, in the fact that the Survey is not altogether to be abandoned, as seemed at one time not unlikely, and that it has been placed in so excellent hands as those of Dr. C. R. Keyes, of the Iowa Geological Survey. It is also gratifying to learn that Mr. Winslow has been engaged to complete his report on the lead and zinc deposits, and that thus a very important

part of the Survey's work will be saved from loss, though the report will doubtless not be brought to the degree of completeness it would have reached under better conditions.

Dr. Keyes will be embarrassed at the outset by severe financial limitations, but we trust that his abilities and tact will win a large success in the end.

T. C. C.

REVIEWS.

The Lafayette Formation. By W. J. McGEE. Twelfth Annual Report of the U. S. Geological Survey, pp. 347-521, 5 maps, 5 plates, 45 text cuts.

THIS brochure almost opens a new chapter in geological history; for although the formation is essentially a surface feature over an area of 100,000 square miles, and only thinly-covered by a mantle of Columbia sands extending over another 150,000 miles, yet the knowledge of these deposits was fragmentary, and they were not correlated as a unit—or interpreted in their bearing on the physical history of the continent, until the appearance of this work.[1] The investigation of the formation was commenced in Mississippi by Professor E. W. Hilgard, who gave it the above name, though the later appellation of "Orange Sand," given by Professor J. M. Safford, in Tennessee, was commonly accepted. Subsequently, McGee's researches along the Atlantic border made known the Appomattox formation, which the author afterwards found to be a northern continuation of Hilgard's Lafayette, or the "Orange Sand." Confusion also arose in the application of the latter name, and by consent of all the authors, Hilgard's original name was adopted.

The report is written in a narrative form in only a few chapters, which are unfortunately not sufficiently subdivided under topical headings to make the arrangement most favorable as a work of reference. On the other hand, the set of maps is particularly clear and explanatory of the text.

"The Lafayette formation may briefly be described as an extensive sheet of loams, clays, and sands of prevailing orange hues, generally massive above, generally stratified below, with local accumulations of gravel along the water-ways", (p. 489). The physical structure is peculiar, although the deposit resembles certain residuary clays derived from the Archean, and from lower Paleozoic limestones, from which it is not always easily distinguished when the gravels are absent, while the gravels

[1] The author had published several advance notices prior to the appearance of the present report.

may resemble those of the sometimes-underlying Potomac, or Tuscaloosa series. Again, the physical features of the whole formation are often reproduced in the overlying Columbia formation. Although the Lafayette is remarkably persistent in its characters over the enormous area, yet care must be exercised in its study. In exposed sections, the surfaces become case-hardened, and stand as vertical walls, on which often the shades of ferruginous oxidation can be seen. The subjacent formations give rise to local variations in the amount of sand, clay, or calcareous matter, which is particularly shown in the agricultural features. This formation once covered the entire coastal plain of both the Atlantic and Gulf margins from Maryland to Mexico, and extended up the Mississippi embayment as far as the mouth of the Ohio, covering a belt extending from the sea margin 50 to 200, or even 500 miles into the interior of the continent. Often, the deposits form only a thin mantle, and away from the valleys ten or twenty feet may be regarded as an average thickness. In the valleys, the accumulations reach 120 feet, and toward the mouth of the Mississippi, 200 feet or more. But the formation has been degraded to an enormous extent by erosion, which has removed it from broad areas, leaving only patches to mark its former extension.

In an introductory chapter, the author has given us an excellent description of the physiography of the coastal plain and of the various geological series in contact with the Lafayette formation. On the Atlantic border, the interior of the coastal plain is sharply defined by the margin of the Piedmont plateau, generally characterized by Archean rocks. This margin is the "fall line," or location of the last great rapids in the descent of the rivers to the sea. Below this line, the streams, which generally cross the plains, are more or less navigable. The interior margin of the Gulf coastal plain is less sharply defined, as it trends across the termination of many different formations of varying characteristics. This same coastal plain extends seaward to the margin of the continental shelf, which is now submerged and extends far seaward of the present coast.

The geology of this plain presents a varied study. Generally speaking, the Potomac (or Tuscaloosa) or later Cretaceous deposits form the interior margin of the belt. This basement is succeeded by many stages of the higher Cretaceous, Eocene, and Miocene accumulations, although the succession is not everywhere complete. No marine fossils higher than the middle Miocene are known on the

coastal plain, except at two or three localities. The topography of all of these formations was greatly modified by erosion during intervening periods of high level of the land, but in general, the successive formations were planed nearly to base level before the succeeding deposits were laid down. This was the condition before the Lafayette epoch, and the seaward slope of the country was more gradual than at present, although the continent was high enough to allow the submerged continental shelf to be a sub-aërial plain. Then came the extensive subsidence and seaward tilting, which allowed the invasion of oceanic waters over the coastal plain, so as to permit of the deposition of the loams even upon the margin of the Piedmont plateau. This subsidence was unequal, least in the region of Cape Hatteras, greater along the South Carolina axis, again diminished in the Gulf region, and greatest along the Rio Grande. The author regards all of these Lafayette deposits as having accumulated at sea level from the land wash brought down by the rivers. Although devoid of marine life, so far as known, this seems the most rational explanation, although the physical characters are very different from those of the earlier Tertiary or Mesozoic deposits, which were laid down after submergence with less decided seaward tilting.

Mr. McGee regards the duration of the epoch of subsidence as short. The succeeding elevation, which carried the country from 100 to 1,000 feet above tide, he regards as much longer. This uplift was not uniform, probably only 100-300 feet at Cape Hatteras, and 1,000 feet at the mouth of the Mississippi, but in undulations such as characterized the previous subsidence; where the greatest depression had taken place, there the greatest elevation followed along the same axes. Moreover, it is apparent from the intensity of erosion that the elevation was greater along the Appalachian and Cumberland plateaus than along the coast, giving greater slope to the rivers than at present. This elevation was unquestionably of long duration and the erosion enormous, removing from the valleys a large proportion of the accumulations of the preceding epochs and cutting through them to depths of 150 feet and upward, and to widths of 10 and 20 miles, even 100 miles in the case of the Mississippi. This the author emphasizes, giving great prominence to the geomorphy from which the post-Lafayette elevation is deduced.

After this long-continued period of degradation, the continent subsided, but not so much as during the Lafayette days, and during

this subsidence the Columbia formation was deposited. Some of its characters are similar to those of the Lafayette, and indeed the latter deposit may often be mistaken for the earlier, where unconformity is not apparent. The Columbia formation covered the lower half of the coastal plain, and partly filled the great valleys which thus became estuaries. These deposits form the "second bottoms" of many of the coastal rivers, particularly on the Gulf slope. In short, the Columbia formation of the South is largely the Lafayette made over, though in the North its materials grade into those of the glacial period.

Following the Columbia submergence the continental margin again rose, even to an altitude above that of modern times, to such an extent as to permit of the clearing out of the valleys to a considerable extent; including those now submerged along the oceanic plateau. Then followed a subsidence to modern conditions. This post-Columbia elevation did not last nearly so long as the post-Lafayette, for 90 per cent. of the accumulations still remain.

The altitudes at which the Lafayette deposits are now found vary. In Maryland they occur at 500 feet; southward they decline so that at Hatteras they occur at 100–200 feet. Along the axis of greatest oscillation in South Carolina the formation rises to 800 feet, but again descends southward so that north of Mobile Bay they rise only 500 feet above tide. Again in Illinois and Arkansas, the loams rise to only 350 and 250, whilst they culminate at 1,000 feet along the Rio Grande. But as river terraces of the streams emptying into the Lafayette sea, the reviewer has met with the extension of the formation in the southern Appalachian at 1,500 to 2,000 feet, thus supporting the author's conclusions as to the greater magnitude of terrestrial undulation in the mountain regions than along the coast.

At Cape Hatteras, the Columbia deposits now rise only 25 feet above tide, but they increase to 300 feet in altitude to the north and again southward, so that in South Carolina they rise to 650 feet. Again they decline to 25 feet above the Gulf in Mobile Bay. Farther southwestward their present elevation is from 100 to 200 feet.

The meager flora of the Lafayette has both Cretaceous and Pleistocene features, and the more meager fauna represents the entire Neocene. The Columbia is regarded as the earliest Pleistocene, and the Lafayette as the later Pliocene, though the author groups it with the Miocene and small areas of marine Pliocene, the whole making the American Neocene. Its biological relations are not known; it is by

its physical characters that the Lafayette formation has been investigated and largely explained.

The author of "The Lafayette Formation" has made one of the most important recent contributions to geological science. Besides his contribution to the geology of an enormous area, the principles of geomorphy are emphasized, and the interpretation of the continental changes of the later Tertiary days are set forth in an original manner, forming one of the most interesting chapters in dynamical geology.

The maps are particularly worthy of attention. The first represents the physiography of the coastal plain, and its relations both with the higher land area and deeper oceanic depression. The next is a colored map showing the distribution of the Lafayette formation and the overlying Columbia. The third map shows the continental area during the Lafayette subsidence; it is both a topographical and hydrographical chart of the physical features of land and sea when 250,000 square miles of the southeastern part of the continent was submerged. It is of special interest. Then follows the topographical map of the high continent during the post-Lafayette elevation, when the continental region was expanded by 100,000 miles or more in excess of that of modern times. The last map shows the continental contraction during the Columbia period—and a very strange looking map it is with the land margin dissected by numerous estuaries, scores or hundreds of miles in length, resulting from the submergence of the great valleys of the south in connection with the tilting of the land toward the South Carolina axis of oscillation.

Although this work was commenced by others, yet the extension and digestion of the whole belongs to the author, and it is a remarkably meritorious work. But in the study of geomorphy, and of the most interesting continental changes, the work is almost entirely original. The whole forms one of the most complete, yet peculiar, chapters of American geology. This review is only sufficient to call attention to a very suggestive report in which, however, there are still some questions left open. The author is to be congratulated on having taken up such an important and interesting but little known subject, and for working it out to such a degree of completion.

J. W. SPENCER.

Elementary Meteorology. By WILLIAM MORRIS DAVIS, Professor of Physical Geography in Harvard College. Boston, U. S. A. Ginn & Co., Publishers, 1894, pp. XII.+355.

THE announcement, made some months ago, that Prof. Davis was about to publish a work on meteorology, was hailed with satisfaction by all those interested in this branch of natural science. The book, which has recently been issued by Ginn & Co., presents the condensed results of the author's reading, observation, and teaching during the last fifteen years. Since it has been prepared by one who is not only eminent as an original investigator, but also as an experienced teacher, it is scientific in its treatment, fully in accord with the latest advances in meteorology, and, at the same time, well fitted for the use of college students of the more advanced years. In so far as the experience of the writer goes, this book would seem to be better adapted to the abilities of juniors and seniors of the majority of our colleges than to the "later years of a high-school course, or the earlier years of a college course," as the author suggests in the preface.

The plan of the book is stated by the author at the outset, as follows: "The origin and uses of the atmosphere are first considered, with its extent and arrangement around the earth. Then, as the winds depend on differences of temperature over the world, the control of the temperature of the atmosphere by the sun is discussed, and the actual distribution and variations of temperature are examined. Next follows an account of the motions of the atmosphere in the general and local winds; in the steady trades of the torrid zone, and in the variable westerly winds of our latitudes. The moisture of the atmosphere is then studied with regard to its origin, its distribution, and its condensation into dew, frost, and clouds. After this, we are led to the discussion of those more or less frequent disturbances, which we place together under the name of storms; some of them being large, like the great cyclones or areas of low pressure on our weather maps; some of them very small, like the destructive tornadoes. The effect of these storms and of other processes in the precipitation of moisture as rain, snow, and hail is next considered. Closing chapters are then given to the succession of atmospheric phenomena that ordinarily follow one another, on which our local variations of weather depend, together with some account of weather prediction; and another on

the recurrent average conditions that we may expect, in successive seasons, repeated year after year, which we call climate."

The above statement gives an idea of the scope and method of treatment of the subject. There are a few points, however, which deserve more particular mention. In chapter III., the distribution over the earth of the insolation, or radiant energy received by the earth, is discussed, and by means of a very ingenious diagram, the amount of insolation for all latitudes for each month of the year is graphically shown. A detailed discussion of the various processes of absorbtion, conduction, radiation, and convection, by means of which the atmosphere gains and loses heat, is given. In the course of this the author takes exception to the statement, so common in most physical geographies, in which the atmosphere is "compared to a trap which allowed sunshine to enter easily to the earth's surface, but prevented the free exit of radiation from the earth." In reality, the coarse-waved radiation from the earth passes out readily without great absorbtion, either by the clear air or the water-vapor, which has been proved to be as poor an absorber as pure dry air.

Again, the exact processes, by which convectional circulation is set up, are clearly brought out, and the incorrectness of such loose statements, as "the air is heated and rises, and the cold air rushes in from either side to fill the vacuum thus formed," is emphasized.

A general review of the distribution of pressures and the circulation of the winds shows the student two particulars, in which the expected arrangement of pressures and motions according to the theory of convection, as applied to the origin of winds, are contradicted by the facts. The polar pressures are high, not low, the highest pressures occur around the tropics, where intermediate pressures were expected, and the winds do not follow the gradients, but are systematically deflected. Either the convection theory is fundamentally wrong as an explanation for the winds, or it needs to be supplemented by some factors up to this time unconsidered. This fact the author brings clearly to the mind of the pupil, who is then led to see that, perhaps, the oblique course of the winds may account for the distribution of pressures at the poles and the tropics. The cause of the oblique course is found in the deflecting influence of the earth's rotation. It is proportionate to the velocity of motion, and increases from zero at the equator to a maximum value at either pole, but it does *not* depend upon the direction in which the body is mov-

ing. In this connection, the author points out another error found in many text-books, namely that the oblique course of the winds is due to a lagging behind, as they move from regions of less to those of greater rotary velocity, and, therefore, that winds traveling due east would not be deflected at all. As was clearly shown by Ferrel, many years ago, both the explanation and its corollary are wrong, although they have appeared in many text-books, even of recent date.

Following the discussion of a competent theory for the general circulation of the winds, there is given a systematic account of the different members of the circulation, and a classification of winds according to cause into (1) planetary, (2) terrestrial, (3) continental, (4) land and sea breezes, (5) mountain and valley breezes, (6) cyclones and other storms, (7) eclipse winds, (8) landslide and avalanche blasts, (9) tidal breezes, (10) volcanic storms.

Chapter X., treating of cyclonic storms and winds, is one of the most interesting and valuable in the book. The tropical cyclones are first considered. The evidence of convectional action in these cyclones is considered, and it is shown that their distribution both in time and place points strongly to the theory that they originate through the overturning of great masses of air, due to unequal heating. But it is clearly pointed out to the pupil that it has not yet been directly shown that the temperature of the cyclonic mass is higher than that of the surrounding atmosphere at corresponding altitudes, a condition which, of course, must be satisfied before convection can take place. If this shall, hereafter, be shown *not* to be the case, the convectional theory will have to be abandoned.

In points like this, Prof. Davis' book is particularly good, for, all along, he has stated clearly not only what is certainly known, what is probable, and what is doubtful, but also what is not known. This prevents the student from forming misconceptions of the subject, or dropping into loose habits of thought.

The extra-tropical cyclones are closely compared with the tropical cyclones, and their points of likeness and difference shown. Two theories for their origin are discussed, and lines are indicated along which the rival theories may, some day, be tested, but here again, the fact is emphasized that much is not yet known, and that positive didactic statements are to be avoided.

Space will not permit even a brief mention of many other points to which we should like to call attention. The subjects of thunderstorms,

rainfall, weather, and climate receive careful consideration. The text is illustrated by many maps and diagrams, of which a number are original. The generalized charts, showing the winds of the Atlantic and Indian Oceans, taken from the atlas of the German Naval Observatory, are particularly valuable. But a few of the diagrams, although showing clearly what they were intended to represent, fall short of the standard of artistic excellence set by the others.

The value of this book lies, if in some things more than in others, in the logical treatment of the subjects, the frequent turning aside from the discussion for the purpose of introducing additional facts in order to correct, modify or substantiate hypotheses, and the clear discrimination, between facts, well-established theories, and working hypotheses. The pupil, who uses this book intelligently, will learn, not only many things about meteorology, but what is far more valuable, true scientific methods of thought, study, and work.

HENRY B. KÜMMEL.

Analytical Abstracts of Current Literature.

SUMMARY OF CURRENT PRE-CAMBRIAN NORTH AMERICAN LITERATURE.[1]

Lawson[2] gives a résumé of the geology of Northeastern Minnesota adjacent to Lake Superior. Surrounding the Lake there are four geological provinces, from the top downward, the Potsdam, Keweenian, Animikie, and Archean.

The Rocks of the Potsdam are flat-lying shaly sandstones, generally of a red color.

The Keweenian occupies the entire Minnesota coast from Duluth to Grand Portage. The series consists in this area of a well stratified series of volcanic flows, having a gentle lakeward dip, which does not generally exceed 10°. The sedimentary formations are represented in the series, but occupy less than one-half per cent of the coast line. The lavas are largely vesicular or amygdaloidal in character, and in those of acid composition in which the vesicular structure is not so well developed are numerous irregular joints. The series has been invaded by many later intrusive masses, which occur as nearly vertical dikes, or more commonly as injected sills which coincide with the planes of stratification of the bedded flows. Since the time of the outflow of the Keweenian rocks, the strata have suffered comparatively little disturbance, the prevalent lakeward dip being probably due to the attitude of the slopes upon which the lavas flowed, rather than entirely to a differential movement of once horizontal strata. The pre-Keweenian labradorite rocks exposed at a number of points were profoundly eroded before the Keweenian was deposited upon them, and they were presumably Archean.

The Animikie rocks occupy the shore of the Lake from Grand Portage to Port Arthur. The series is composed altogether of sedimentary strata, and consists mainly of fine-grained sandstones, which are locally quartzites, carbonaceous shales or slates, and in small part of cherts and jaspers, beds of carbonate of iron, hematite and magnetite, conglomerate, and occasional lenses of non-ferruginous carbonate in the slates. Except in local instances

[1]Continued from p. 118.

[2]Sketch of the Coastal Topography of the North Side of Lake Superior with Special Reference to the Abandoned Strands of Lake Warren, by A. C. Lawson. In 20th Annual Rep. Geol. & Nat. Hist, Sur., Minn. pp. 181-289.

the rocks have been disturbed very little from the horizontal, the average dip of the strata being in a southeasterly direction at an angle probably not exceeding 5 degrees. Intrusive rocks are abundantly present as sills lying parallel to the stratification, resembling contemporaneous beds, and as vertical dikes, some of which have been observed in continuity with the sills. Faulting is a common occurrence in the Animikie, many scarps being due primarily to this cause.

The Archean shares the coast line with the Animikie and Keweenian from the vicinity of Port Arthur to the eastern end of Nipigon Bay, and beyond this point to the outlet of the lake is the dominant series. This complex consists of two divisions: 1) a great volume of profoundly altered sedimentary and volcanic rocks, characteristically schistose or in the form of massive greenstones, which have suffered intense disturbance, and which correspond to what has been designated the Ontarian system, and 2) immense batholites of irruptive gneiss and granite, which have invaded the rocks of the Ontarian system from below in the most irregular fashion, corresponding to that division of the Archean which is commonly recognized as Laurentian. These Laurentian rocks exhibit only to a very subordinate extent those evidences of disturbances and deformation which are so abundantly apparent in the schists which they have invaded. The Laurentian gneisses and granites occupy much more of the shore than do the metamorphic and schistose rocks of the Ontarian. Both divisions of the formation are cut by basic dikes, which, as a rule, do not exceed 100 feet in width, and are vertical or nearly so. The Archean forms the basement upon which the Animikie rests in glaring unconformity, the actual superposition being observed at several points, with the Keweenian lying flat on the latter. Very frequently, however, the Keweenian reposes directly upon the Archean.

Van Hise[1] gives an historical sketch of the Lake Superior region to Cambrian time. The five divisions of this region are the Basement Complex or Archean; The Lower Huronian, Upper Huronian and Keweenawan, the last three together constituting the Algonkian, and the Lake Superior Cambrian Sandstone. Each of these divisions are separated by unconformities.

The Basement Complex consists mainly of granites, gneissoid granites, and of finely foliated dark colored banded gneiss or schist. The relations which obtain between the two divisions are frequently those of intrusion, the granites and gneissoid granites being the later igneous rocks. There is no evidence that any of the dark colored schists are sedimentary, but it is certain, if a massive granular structure be proof of an igneous origin, that a part of them are eruptive, for between the two are gradations.

[1]An Historical Sketch of the Lake Superior Region to Cambrian Time, by C. R. Van Hise. In JOURN. OF GEOL., Vol. I, No. 2, pp. 113-128. With geological map.

The well known characteristic rocks of the Lower Huronian are 1) conglomerates, quartzites, quartz-schists, and mica-schists, 2) limestones, 3) various ferruginous schists, 4) basic and acid eruptives, which occur both as deep seated and as effusive rocks. The order given, with the exception of the eruptives, is the order of age from the base upward. In the Lower Huronian are placed the Lower Vermilion, Lower Marquette, Lower Felch Mountain, Lower Menominee, the cherty limestone formation of the Penokee district, and also probably the Kaministiquia series of Ontario, and the Black River Falls series of Wisconsin.

The formations of the Upper Huronian are 1) a basement slate and quartzite, frequently bearing basal conglomerates, 2) an iron-bearing formation, consisting originally of lean cherty carbonate of iron, calcium and magnesium, and 3) an upper slate. Associated with the sedimentaries in the Michigamme, Crystal Falls, and other districts, are great volcanic series, comprising greenstones, agglomerates, greenstone conglomerates, volcanic ash, and amygdaloids. Where these occur the orderly succession is destroyed. Included in the Upper Huronian are the Penokee, Mesabi, Animikie, Upper Marquette, Upper Menominee, and Upper Felch Mountain districts.

The Keweenawan consists of interstratified lavas, sandstones and conglomerates. The lavas are prevalent at the lower part of the series; interstratifications of the two occur in the middle portions; and the pure detritals exclude the volcanics in the upper portion of the series.

The Lower Huronian is largely crystalline, the Upper Huronian semi-crystalline, and the Keweenawan simply cemented. Locally along axes of intense plication, both the Lower Huronion and Upper Huronian have been transformed into completely crystalline schists. The Cambrian of Lake Superior is a horizontal sandstone, and rests unconformably upon all the preceding.

Smyth[1] describes a contact between the lower quartzite of the Lower Huronian and the underlying granite at Republic, Michigan. Below the lowest exposures of magnetite-actinolite-schist are exposures of the lower quartzite, and below this, hanging upon the northern flank of the granite, is a conglomerate containing very numerous well rounded bowlders of granite and gneiss, identical with the rocks immediatiately below. It is concluded that this conglomerate from its position can not possibly belong to the Upper Huronian, and that it is a true basal conglomerate of the Lower Huronian.

Winchell, N. H.,[2] gives the following as the general consensus of opinions

[1] A contact between the Lower Huronian and the Underlying Granite in the Republic Trough, near Republic, Mich, by H. L. Smyth, JOURN. OF GEOL., Vol. I., No. 3, pp. 268-274.

[2] The Crystalline Rocks, by N. H. Winchell. In 20th Annual Rep. Geol. & Nat. Hist. Sur., Minn., 1891, pp. 1-28.

of several geologists as to the descending succession of the rocks of Northeastern Minnesota.

1. Keweenawan or Nipigon series unconformably beneath rocks bearing the "Dikellocephalus" fauna, and consisting of fragmental and eruptive beds, the upper portions being almost entirely red sandstones.

2. Alternating beds of eruptive sheets and fragmental rocks. The fragmentals are thin bedded slates, actinolite-schists, magnetitic jaspers, cherts and quartzites. The sheets are ordinary eruptives or pyroclastics.

3. Immense quantities of true gabbro often bearing Titaniferous magnetite, are associated with contemporaneous felsites, quartz-porphyries and red granites. This gabbro includes several masses of the next older strata, particularly the Pewabic quartzite.

4. The Animikie. This series is characterized by a great quartzite associated with the iron ores and cherts. The quartzite (Pewabic) lies unconformably on all the older rocks. It often is conglomeratic, bearing debris of the underlying formations. Within it is mingled volcanic tuffs from contemporaneous eruptions. The Pewabic quartzite includes that of Pokegama Falls on the Mississippi River, and of Pipestone County. In the vicinity of contemporaneous volcanic disturbances its grain is fine, like jaspilite, and sometimes it has acquired a dense crystalline structure from contact with the gabbro.

5. The Keewatin. This is a volcanic series of great thickness, being composed mainly of volcanic tuffs, presenting more or less evidence of aqueous sedimentation, but conglomerates, graywackes, quartzitic schists, and glossy serpentinous schists are present. The Kawishiwin formation, apparently the upper member of the series, embraces the great bulk of the greenstones, chloritic schists, jaspers, and hematites. The iron ores are in lenticular lodes, and stand upright conformable with the general position of the rocks.

6. The Keewatin series becomes more crystalline towards the bottom, and passes conformably into completely crystalline mica-schists and hornblende-schists, which are named the Vermilion series. The rocks are usually stratiform, contain magnetic iron ore, and embrace some dark massive greenstone belts, in which no stratification bands are visible.

7. The Laurentian. When not disturbed by upheaval the Vermilion schists pass into Laurentian gneiss, there being a gradual increase in the feldspathic and siliceous ingredients. Even after the Laurentian characters are apparently fully established, conformable bands of Vermilion schists reappear: from which it is plain that the base of the Vermilion is an uncertain plane, which can not be located exactly. This normal passage from the Vermilion to the Laurentian is frequently disturbed by the intrusion of numerous dikes of light colored granitic and basic rocks. These were both in a fluid state, the only non-fluid rocks being the schists which are embraced

within them in isolated pieces. In a similar manner small areas of Laurentian granite, sometimes directly in contact with the schists, have the imperfectly crystalline condition of the Keewatin.

Nos. 3 and 4 are separable from No. 2 by divergence in dip and strike, as well as by a marked difference of lithology. There is consequently some evidence of unconformity between them. Below No. 4 is a great physical break, which separates Nos. 1, 2, 3, and 4 from 5, 6 and 7 throughout the Lake Superior region. This break is the greatest erosion interval which has been discovered in Palæozoic geology. 1, 2, 3, and 4 together constitute the Taconic, Nos. 5, 6, and 7 constitute the fundamental complex or Archean, which is a unit in its grander features.

The structure and origin of the foregoing series are considered in some detail. It is concluded that stratification can always be discriminated from schistosity or slaty cleavage by the varying shades of color bands which sweep across the surface of the rocks, and by gradations in the kind and size of grains across the bands. These layers may vary from 1-16 of an inch to several inches or several feet across.

Comments.—As used by the United States Geologists, Nos. 1, 2 and 3, are included in the Keweenawan. These divisions and the break between 2 and 3 are recognized by Irving, so that the difference is merely one of nomenclature. No. 4 is Upper Huronian; No. 5 is Lower Huronian; and Nos. 6 and 7 are the Basement Complex or Archean. The break between the Lower Huronian and the Basement Complex is perfectly clear on the south shore of Lake Superior, and is found by Lawson at the base of the Keewatin in Ontario. In Minnesota, Professor Winchell, on the contrary, regards the Keewatin as grading down into the underlying series. Many geologists would disagree with the statement that stratification can always be discriminated from schistosity or slaty cleavage by either of the criteria mentioned or by both combined.

Grant,[1] in 1893, publishes his note book, made on a trip in Northeastern Minnesota. The areas visited were those of the Kawishiwi river, Snow Bank lake, Kekequabic lake, and Saganaga lake. In the study of these areas there was no evidence found of a transition from semi-crystalline and crystalline schists into granite. On the other hand, abundant evidence was found of the eruptive nature of the granite rocks into the surrounding sediments. The gneissic and so-called bedded structure in the granitic rocks is not as common as has been supposed, the structure usually being truly granitic. The Kawishiwi river and Snow Bank lake massive rocks are hornblende syenites. The Saganaga rock is a coarse hornblende granite. That

[1] Field Observations on Certain Granitic Areas in Northeastern Minnesota, by U. S. GRANT. In 20th Annual Rep. Geol. and Nat. Hist. Sur. Minn., pp. 35-110.

around Kekequabic lake is a pyroxene granite, and associated with it is peculiar pyroxene-granite-porphyry. The intrusive character of the granite is particularly well shown between Sec. 31 and 32, T. 63 N., R. 10 W., near Clearwater lake, and in the S. E. ¼ of the S. W. ¼ Sec. 26, T. 64 N., R. 9 W., on the west shore of Snow Bank lake. Along the Kawishiwi river, the rocks mapped comprise gabbro, syenite, mica-schist, graywacke, etc.; greenstone and quartz-porphyry. The gabbro is the most recent, and covers part of the older rocks. The syenite is older than the gabbro, and is younger than the greenstone and mica-schist, both of which it cuts. The mica-schists, graywackes, etc., are vertical, and have a general east northeast strike. These have been formerly mapped as belonging to the Vermilion series, but there seems to be good reason for putting all of this type of rock in the area mapped into the Keewatin. The greenstone is presumably of Keewatin age, and is probably younger than the mica-schists, graywackes, etc. Quartz porphyry dikes are found cutting the greenstones in several places, but they have not been seen in the other rocks in the immediate vicinity.

Comments.—The conclusions of this report differ from the general succession given by Professor Winchell in the fundamental point that there is no gradation between the granitic rocks and the metamorphosed sedimentary rocks. Also all of the metamorphosed sedimentary rocks are regarded as belonging to the Keewatin (Lower Huronian?) while the Vermilion schists are not found. If there now exists in this area the original basement upon which the sedimentary rocks were deposited, this has not been found. It is of course possible that such a Basement Complex does not exist in the Kawishiwi river area, the one which was most closely studied, nor even in the entire region, but this is not thought probable.

Winchell (H. V.)[1] describes the Mesabi iron range of Minnesota. The range extends from the Canadian boundary, a little south of west to the Mississippi river, a distance of 140 miles or more, but is concealed for a part of this distance by the later gabbro overflow. The succession of the Mesabi in descending order is:

1. Gabbro unconformably on all the following ..... Taconic.
2. Black slates Animikie ..... Taconic.
3. Greenish siliceous slates and cherts ..... Taconic.
4. Iron ore and taconyte horizon ..... Taconic.
5. Quartzite unconformable on 6 and 7 ..... Taconic.
6. Green schists of the Keewatin ..... Archean.
7. Granite or syenite of the Giant's Range ..... Archean.

The granite of the Giant's Range is bounded on the north by a belt of crystalline mica-schists and hornblende-schists, and on the south seems to

[1] The Mesabi Iron Range, by H. V. WINCHELL. In 20th Annual Rep. Minn. Geol. Sur., pp. 11-180.

have a direct transition into the green schists of the Keewatin. The green schist has a nearly vertical cleavage. The schists do not always follow the course of the granite range. They are unconformably covered in many places by the quartzite. The quartzite never has a high dip. Near the base it contains pebbles of quartz and granite, as well as jasper and greenstone. This quartzite is correlated with the Pewabic quartzite of the Gunflint lake, the Pokegama quartzite of the Mississippi river, that of Sioux Falls, South Dakota, and that of Baraboo, Wisconsin. Conformable with the quartzite is the iron ore and taconyte horizon. The strata are siliceous and calcareous, and are banded with oxide of iron in beds of variable length and thickness. The ore is sometimes magnetite and sometimes hematite. To the banded jaspery quartzite associated with the ore the term taconyte is applied. The greenish siliceous slates or cherts constitute a transition stage between the rocks of the iron horizon and the black slates. There is a considerable mixture of greenish material, apparently of eruptive origin. The greater part of the rock is a red, yellow, black, white, or green chert, sometimes having a thickness of 200 or 300 feet. It often has a peculiar brecciated appearance, having been shattered into angular fragments, and recemented by the same amorphous silica. The same fracturing is also visible in the iron ore. The siliceous slates and cherts pass upward into a carbonaceous argillite of great thickness, having a dip varying from the horizontal to 20° to the south or southwest. Locally the dip is as high as 45°, in which case the ore deposits lie close to the green schists. The gabbro flow is over all of the previous strata. The effect of the heat on the molten gabbro was to make the iron ore which already existed in the rocks hard and magnetic. There is good reason to believe that the iron ore deposits in their present condition have been principally formed since the gabbro overflow. The ore deposits occur as regular beds, which lie in almost their original positions, usually having a dip of less than 30° and passing into the jaspery quartzite or taconyte in three directions, and occasionally on all sides. The theory of Irving as to the origin of the Gogebic ores is partially adopted. The quartzite is impervious to surface infiltration. The ore is regarded as produced by chemical replacement of some mineral, chiefly silica, by oxide of iron. As evidence of this, all stages of the process may be seen. Iron carbonate is found in the Mesabi rocks, but it does not appear in sufficient quantity to permit the assumption that the source of the ore was originally a carbonate. The solvent for the silica was probably carbon dioxide, and its source may have been the atmosphere, the black slates, recently decaying vegetation, or the ore deposits higher up the hill. The silica removed from the location of the iron ores has been added to the grains of quartz in the quartzite, has been deposited as chalcedonic and flinty silica, and has been deposited in cracks and fissures in the slate, which lie at a lower elevation, but stratigraphically above the ore. The source of

the iron is believed to have been chemical and mechanical oceanic deposits, which have simply concentrated in the present situation, perhaps from rocks now completely removed by erosion. The water which brought in the iron ore to supply the place of the silica taken away in solution followed the natural drainage courses, either the drainage slopes or else the joints. The Giant's Range is regarded as having been uplifted at the time of the gabbro outflows, and to have been caused by them.

Comments.—The succession of the Mesabi range is almost identical with that given by the reviewer for the Penokee-Gogebic district. At the base of the Penokee series constituting the basement complex are granite, syenite, and various green schists. These correspond to Nos. 6 and 7 of the Mesabi. Resting unconformably upon this basement complex is the quartz slate member, consisting largely of quartzite, corresponding to Winchell's No. 5. Resting conformably on the quartzite is the iron-bearing member, which has two main horizons, the lower carrying the ore bodies, and the other free from ore bodies. This iron-bearing formation of non-fragmental origin consists of cherts, slates, and jaspers, all more or less ferruginous. It evidently corresponds exactly to Winchell's Nos. 3 and 4, his "taconyte" being a new name proposed for ferruginous chert, or what the miners call "soft ore jasper." Overlying the iron-bearing member is the upper slate member, which is identical in character with Winchell's Animikie black slates. Unconformably upon the black slates is the Keweenawan series, which, in the Penokee area, has different characters in different places, but to which Winchell's No. 1 gabbro belongs. There thus appears to be absolute identity as to succession, and also the structural breaks occur in precisely the same horizons in the Penokee and Mesabi districts. The facts given as to the iron ores, apart from theory, correspond in nearly every respect with the occurrences in the Penokee district. The differences are that the basement impervious formation in the Mesabi range is not a dike rock, but the pitching quartzite alone. The source of the iron ore is said to be an oceanic deposit, but while the presence of iron carbonate is asserted, it is denied that it can be assumed that it has been present in sufficient quantity to furnish ore beds. The cherty iron carbonate of the Gogebic range, the source of the ore, was a water deposited sediment.

The presence of three like unconformable series in the Penokee and Mesabi districts, the identical succession of the iron-bearing series, the remarkable similarity of the rocks of each of the corresponding formations, and the nearly identical history of the ore-deposits, is a remarkable instance of like conditions prevailing simultaneously in a geological basin throughout a wide area.

Hulst[1] gives a resumé of the general geology of the Menominee district as explained by Brooks, and gives detailed sections of several of the mines. The descending succession at the Millie Ore Body and Chapin Mine is as follows:

Quartzite Jasper Quartzite Quartzite and jasper Quartzite, slate, and jasper Slate Quartzite and slate Quartzite and jasper	140 feet.
Banded ore, containing Millie Ore Body	300 feet
Quartzite and slate Slate	55 feet.
Jasper	170 feet.
Ore body Gray slate	75 feet.
Ore Gray slate Jasper Gray slate Jasper G Gray slate Jasper Ore Gray slate Limestone	185 feet.

The descending succession in the Pewabic Mine is as follows:

Jasper and ore, containing Pewabic Ore Body	215 feet.
Gray slates	112 feet.
Quartz Gray slate Quartzite	77 feet.
Quartz and slate Slate conglomerate	50 feet.
Red slate	77 feet.
Quartz and gray slate Quartzite Quartz and sand Slate conglomerate Quartz conglomerate	116 feet.
Red slate Jasper Red, gray slate Limestone.	

[1] The Geology of that Portion of the Menominee Range East of Menominee river, NELSON P. HULST. In Proceedings Lake Superior Mining Institute for March, 1893, pp. 19-29.

The ore bodies are found in beds of banded lean jasper, which is always an invariable associate of the richer ore, and it may occur anywhere within the jaspery horizon. The rich ore often appears to be a part and parcel of the general stratification of the lean ore encompassing it. Not infrequently one finds spots which are apparently in the transition state from the lean jaspery ore, as though the ore body was charged with a solution, which was gradually dissolving out the silica from the adjacent jasper. There is invariably a notable pitch to the ore bodies, and it is generally to the west at an angle of from 30° to 50°. Connected with some of the ore bodies are well defined hanging or foot-walls of so-called soapstone, but often when there are no well-defined walls, the ore body being found in the jasper, the ore is quite sure to carry a minimum of phosphorus, as exemplified at the Millie, Pewabic, Cyclops, Aragon, and S. E. Vulcan mines. The productive portions of the range appear to be located at the points where the formation has been faulted, eroded deeply, or sharply folded.

Comments.—The sections give additional evidence that in the Menominee district, as in the Marquette, there are two unconformable series. The Chapin, Ludington, and Hamilton appear to belong to the Lower Huronian. The horizon of quartzite, slate and conglomerate is evidently the basal conglomerate of the Upper Huronian. The Mille, Pewabic, and similar ore bodies, are in the Upper Huronian. That the ore bodies occur in disturbed areas, and frequently rest upon soapstone or other impervious formations, accords perfectly with what has been previously ascertained as to the manner of concentration of the Lake Superior iron ores.

Van Hise[1] gives the following as the ascending succession in the iron-producing part of the Marquette district: (1) Basement Complex, consisting of granites, gneisses, schists, and greenstone-conglomerates, the whole intricately intermingled, and the schists intruded by the granites and gneissoid granites; unconformity: (2) Lower Marquette series, having at its base a conglomerate and quartzite formation, upon which rests an iron-bearing formation; unconformity; Upper Marquette series, which looked at broadly is a great shale, mica-slate and mica-schist formation, but it often has at its base quartzites and conglomerates, and several hundred or a thousand feet from its base an iron-bearing formation similar to that of the Lower Marquette series. Included within both the Lower and Upper Marquette series are many basic intrusive dikes and bosses of diabase, and also contemporaneous volcanics, which are largely tufaceous

At the east end of the Marquette district is the Mesnard series, the position of which has not as yet been determined.

[1] The Succession in the Marquette Iron District of Michigan, by C. R. VAN HISE. Bull. Geol. Soc. of Am., Vol. V., 1893, pp. 5–6.

Van Hise[1] describes the Huronian volcanics south of Lake Superior. These include both lavas and tufas interstratified with each other and with contemporaneous clastics. Among the lavas are amygdaloids, the amygdules of which are in certain cases jasper similar to that of the iron formation adjacent, and believed to have been formed at the same jasper forming period. The volcanics are much more altered than those of the Keweenawan. They are found in various places, but the most extensive areas are in the Gogebic district west of Gogebic lake, and in the Michigamme district north of Crystal Falls. In the first locality the series is 7,000 or 8,000 feet in thickness. This great mass of material was piled up, while to the west 700 to 800 feet of the sediments of the iron-bearing formation were accumulating. In this district, therefore, at the same time there was being deposited the ordinary sediments of the area and locally a volcanic series of a wholly different character.

[2]Bayley describes actinolite-magnetite-schist from the Mesabé range of Minnesota. This rock differs from the corresponding schists of the Penokee series only in that quartz is rare and hematite is absent.

C. R. VAN HISE.

[1]The Huronian Volcanics South of Lake Superior, by C. R. VAN HISE. Bull. Geol. Soc. of Am., Vol. IV., pp. 435–36.

[2]Actinolite-magnetite-schists from the Mesabé Iron Range, in Northeastern Minnesota, by W. S. BAYLEY. Am. Jour. of Sci., Vol. XLVI., No. 273, Sept., 1893, pp. 176–180.